BEEF FLAVOR ATTRIBUTES AND CONSUMER PERCEPTION ON LIGHT BEEF EATERS

A Thesis

by

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ABSTRACT

Beef flavor is an important component of consumer acceptance and overall liking; however, it is complex and is composed of multiple attributes. Additionally, consumer opinions vary in factors that drive acceptance and it has been hypothesized that beef flavor drivers may differ for consumers who eat beef 1 to 2 times per week compared to consumers that eat beef more frequently. Our objectives were to create varying levels of positive and negative beef flavor attributes, measure these attributes with an expert trained meat descriptive flavor panel, identify the volatile compounds, and measure consumer liking for light beef eaters, and to understand the relationships between trained descriptive flavor attributes, volatile flavor compounds, beef chemical attributes and light beef eater consumer liking.

Levels of positive and negative beef flavor attributes were created by selecting Choice top loins, high pH top loins (pH ≥ 6.0), Select top sirloin butts, Choice tenderloins, Select bottom rounds, and Choice bottom rounds from 10 beef carcasses. Cuts were cooked to 58 °C or 80 °C utilizing a George Forman grill (steaks), food-service grill (steaks), or crock-pot (roasts). Trained beef descriptive flavor and texture attributes, consumer liking (n = 80 per city in Olathe, KS; State College, PA; and Portland, OR), and gas chromatography-mass spectrometry-olfactometry (GC-MS-O) were utilized to measure flavor. Warner Bratzler shear force; fatty acid composition; non-heme iron and myoglobin content; pH; and fat and moisture analysis were determined to understand chemical component relationships to the aforementioned beef flavor measures.

Cooking method, cut, and internal temperature impacted beef descriptive flavor and texture attributes and consumer liking ratings ($P \leq 0.05$). Beef identity was higher in Choice tenderloin steaks, Choice top loin steaks, High pH top loin steaks and Select top sirloin steaks cooked on the grill to 80°C ($P \leq 0.05$). Consumers rated Choice tenderloin steaks and Select top sirloin steaks cooked on the grill to either 58 or 80°C highest for overall, overall flavor, beef flavor, and grill flavor liking ($P \leq 0.05$). As brown/roasted and fat-like increased, consumer liking increased ($P \leq 0.05$). Aromatic volatile compounds (n = 248) were identified. Fifteen aromatic volatile chemicals accounted for 57% ($P \leq 0.05$) of consumer overall liking. Partial least squares regression ($r^2 = 0.87$) showed relationships between trained descriptive flavor and texture attributes, consumer liking and volatile aromatic chemical compounds.

When beef flavor differed as determined by descriptive beef flavor attributes or aromatic volatile compounds, consumer liking was impacted for light beef eaters. Key aromatic volatile compounds or descriptive flavor attributes could be used to increase consumer overall liking for light beefeaters.

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CHAPTER I

INTRODUCTION

The beef industry is constantly researching beef consumers' desires in order to produce a product that better fits their needs. Beef flavor has been defined as an important component of beef demand. Research shows that consumers rate flavor as the most important attribute for beef palatability (Huffman et al., 1996; Miller et al., 1995; Reicks et al., 2011). Recent research results provided highly predictive regression equations that identified volatile compounds responsible for major positive beef sensory flavor attributes (Glascock, 2014). Knowing this, the importance of further research into the beef flavor component of beef palatability is necessary as it is a very complex factor.

Beef flavor is not a single attribute, but is multiple attributes. The beef industry took the first big step in addressing beef flavor by funding the development of the beef flavor lexicon (Adhikari et al., 2011) that identified major and minor beef flavor descriptors. It would be extremely difficult to develop systems to identify beef flavor if we did not know what makes up beef flavor or how we perceive beef flavor. Since the beef lexicon has been developed, understanding what compounds are responsible for each attribute in the lexicon is made possible. Miller and Kerth (2012) looked further into beef flavor by determining that multiple chemical compounds contributed to each attribute and then comprised data to more closely identify key aromatic, volatile flavor compounds in future studies. Glascock (2014) identified groups of volatile flavor compounds that may help to narrow what compounds can be used to drive flavor differences. Understanding what chemical compounds are responsible for specific beef flavor attributes, can be used to control, mask, enhance or reduce specific flavor compounds to manage beef flavor. Glascock (2014) showed that high heat or extended cookery increased the production of Maillard reaction products, thus increasing overall liking. Kerth et al. (2015) examined different levels of Maillard reaction products on steaks and the impact of these compounds on flavor chemistry. Kerth et al. (2015) showed that varying levels of steak thickness and cook surface temperatures to a consistent degree of doneness created aromatic volatiles that were characteristic of various beef lexicon descriptors.

The objectives of this project were to create varying levels of beef flavor attributes by selecting six different cuts from Choice and Select carcasses. Cuts were prepared using three different cooking methods at different degrees of doneness. Cuts were evaluated using an expert trained meat flavor panel, and measured volatile compounds using GC/MS/O to explain the chemicals in beef flavor, consumer liking for light beef eaters, and then understand consumer attitudes using one-on-one consumer interviews. Warner-Bratzler shear force, fatty acid composition, non-heme iron content, myoglobin content, pH, and fat and moisture analysis were determined and correlated to chemical properties of the raw beef to the flavor of the cooked beef. This allowed consumer positive and negative flavor attributes to be tied with the trained panel beef lexicon and chemicals that contribute to beef flavor.

It was hypothesized that beef flavor attributes can be characterized as positive or negative across consumer segments and that these flavor attributes may be different for light beefeaters.

This hypothesis is important because if the industry can understand what volatile chemical compounds are associated with beef flavor attributes for consumer segments and which attributes are perceived as positive, the industry can more effectively market beef with maximum positive flavors to light beef eaters as well as differing consumer segments. With this research, data could be used to improve the overall flavor of beef presented to all protein consumers.

CHAPTER II

LITERATURE REVIEW

Biological Response to Flavor

The perception of flavor is comprised of the sensory combination and integration of odors, tastes, oral irritations, thermal sensations, and mouthfeels that arise from a particular food (Spanier et al., 2001). However, Meilgaard et al. (2007) defined flavor as the sum of perceptions resulting from stimulation of the sense ends that are grouped together at the entrance of the alimentary and respiratory tracts. Meilgaard also stated that it is important to note that flavor does not include appearance or texture. When conducting practical sensory analyses, flavor is restricted to the impressions perceived via the chemical senses from a product, including: aromas; tastes or gustatory perceptions (the sensation that results when taste buds in the tongue and throat convey information about the chemical composition of a soluble stimulus) caused by water-soluble compounds in the mouth; and the chemical-feeling factors that stimulate nerve ends in the soft membranes of the mucosal and nasal cavities (Meilgaard et al., 2007). There are five main tastes: bitter, salty, sweet, sour, and umami (savory), and all the varieties of flavor are a combination of some or all of these basic tastes. Sensory evaluation is concerned with the human response to physical stimuli. A stimulus first contacts the mouth, at which point nerve signals are generated, integrated in the chorda tympani and sent to the brain. The brain then processes the information, and then it organizes, analyzes and interprets the sensations into perceptions. Once the stimulus is recognized, the brain formulates a response (Civille and Oftedal, 2012).

Aromas are the volatiles perceived by the olfactory system from a substance in the mouth via posterior nares (Meilgaard et al., 1999). Once the aromas interact with the olfactory receptor neurons, the axons arising from the receptor cells project directly to neurons in the olfactory bulb, which in turn, projects to the pyriform cortex in the temporal lobe of the brain. What makes the olfactory system unique is that among the sensory systems, it does not entail a thalamic delay en route to process the information. Further processing in the various regions of the brain allows the aroma to be identified and initiates responses to the olfactory stimuli, thus characterizing a “smell” (Meilgaard et al., 2007). Panelist may have adaptation and fatigue when evaluating the aromas of a product lowering their ability to perceive differences. Also, there is the opportunity for contact with the volatile being too brief, not allowing a panelist time to accurately characterize and describe the aromatic event. Panelist variation is typically one of the biggest problems due to the large amount of variance that can occur.

Beef Flavor

Beef flavor is very complex and is made up of several attributes. It results from both the composition of the raw meat as well as compounds developed from cooking. The distribution of flavors and their precursors between beef solids and juices was described by Crocker (1948). With this information, Hornstein et al. (1960) did some of the original research on beef flavor. Hornstein et al. (1960) showed that hamburgers prepared from water-extracted ground beef, were essentially tasteless and odorless. On the other hand, the water extract developed a beef aroma when concentrated and heated; thus, discovering that the main flavor contributors were water-soluble. Hornstein et al.

(1960) agreed with Crocker (1948) who stated the flavor of the raw meat resides mostly in the juice (Crocker, 1948). Further understanding of beef flavor is important to the beef industry to increase beef demand. Advancements in beef flavor came from the development of the whole muscle beef flavor lexicon and using it in combination with the gas chromatography (GC) and mass spectrometry (MS) system with olfactory ports (Adhikari et al., 2011; Glascock, 2014). This allows for volatile compounds to be identified as well as quantified.

Flavor research has been conducted to determine which chemical compounds are responsible for positive or negative flavors in beef (Glascock, 2014; Miller, 2010; Miller and Kerth 2012). After understanding what chemical compounds are responsible for specific beef flavor attributes, this information can be used to control, mask, enhance or reduce specific flavor compounds to manage beef flavor. Positive beef flavors from the beef lexicon have been considered to be beefy, brown/roasted, bloody/serumy, fat-like, sweet, salty and umami (Miller and Kerth, 2012). Other flavor attributes that are generally considered negative are metallic, liver-like, sour, barnyard, musty-earthy/humus and bitter. Beefy, browned/roasted, bloody/serumy, sweet, salty and umami are associated with the lean portion of beef; fat-like, liver-like, metallic and bitter are associated with the lipid portion. Liver-like and metallic also are associated with the myoglobin content, beef with higher pH and with beef where the fat has oxidized (Miller and Kerth, 2012). Barnyard and musty-earthy/humus are found at slightly higher levels in roasts and may be components of positive flavors when combined with beefy, brown/roasted and umami attributes (Miller and Kerth, 2012).

Beef Flavor Development

As beef flavor is very complex and made up of several different attributes, beef also is made up of many components that help the muscle function properly when alive. Meat contains about 75% water, 18% proteins, 4% lipids, 1% carbohydrates, 1% minerals, and 1% vitamins (Aberle et al., 2001). Proteins, lipids and carbohydrates play the largest roles in beef flavor development, because they include several compounds that can develop into important flavors when cooked. Those flavors are roasted, fatty, boiled, species-specific aromas, as well as the characteristic meaty aromas (Mottram, 1998). Mottram (1998) divided flavor precursors into two major categories: water-soluble components and lipids. Flavor compounds can be volatile and nonvolatile, meaning if the flavor can be evaporated in the air as a gas (volatile) or not. Volatile compounds contribute most to flavor while non-volatile compounds do not contribute as much to flavor. Beef flavor attributes are derived by chemical reactions within beef during cooking. The chemical components of beef flavor are volatile compounds that are sensed by the olfactory bulb by humans during chewing. Of these volatile compounds are aroma compounds that can be detected by humans. Aromatic compounds are a large class of unsaturated chemical compounds characterized by one or more planar rings of atoms joined by covalent bonds of two different kinds.

The water-soluble components of beef flavor are: amino acids, carbohydrates, nucleotides, peptides, and nitrogenous compounds, such as thiamine. The two main precursors to the water-soluble aromatic flavor components are cysteine and ribose. Cysteine is a sulfuric compound that, upon heating with ribose, glucose or xylose, produces a meat-like flavor (Morton et al., 1960). The major chemical reactions for beef flavor occur in the lean and fat components. Flavor chemistry research (Hurrell, 1992; Mottram, 1993; Shahidi, 1994) has shown that lean flavors are associated with reactions between reducing sugars (mainly ribose) and amino acids during cooking, called the Maillard reaction. This is why raw beef is not beefy, but cooked beef is. Cysteine also plays an important role in Strecker degradation, which will be addressed in the Maillard section. Ribose is also one of the main sugars in muscle and is associated with the ribonucleotides found in RNA, DNA, ATP. The basic tastes also stem from the many compounds with the muscle. The sugars in beef (glucose, ribose, and fructose) give beef its sweet flavor, while sourness comes from compounds such as aspartic acid or glutamic acid. Saltiness comes from inorganic salts in the meat and the sodium salts from glutamate and aspartate. Bitter tastes are thought to be a combination of compounds such as hypoxanthine with anserine, as well as carnosine and other peptides or L-amino acids. The savory/broth-like characteristic of umami is from glutamic acid and monosodium glutamate (Shahidi, 1994). The thermal degradation of thiamine produces important compounds that are part of developing a meaty flavor; the most significant compounds is 4-methyl-5-(2-hydroxyethyl) thiazole (Van der Linde et al., 1979). Heterocyclic compounds, especially those containing sulfur, are important flavor compounds produced in the Maillard reaction providing savory, meaty, roast and boiled flavors (Mottram, 1998).

An examination of the literature (Manley and Choudhury, 1999; Mottram, 1998; Shahidi, 1994) relating to the volatile compounds found in meat, shows that over 1,000 volatile compounds have been identified. A much larger number of the compounds found in meat have been identified in beef than the other meats (Mottram, 1998). Several hundred of those volatile compounds are derived from lipid degradation and have been found in cooked meat, including: aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids and esters, as well as aromatic compounds, especially hydrocarbons. Saturated and unsaturated aldehydes, from lipid autoxidation, are major contributors to the volatile profile of cooked meats. These compounds are a result of the oxidation of the fatty acid components of lipids and undergo reactions capable of producing rancid off-flavors during long-term storage. However, in cooked meat, the reactions occur quickly and contribute to positive flavors (Mottram, 1998).

The lipid in muscle consists primarily of fatty acids, phospholipids, and triglycerides. Phospholipids are essential structural components of all cells and contain a much higher proportion of unsaturated fatty acids than the triglycerides, including significant amounts of polyunsaturated fatty acids such as arachidonic acid (20:4) (Mottram, 1998). They are the structural component of the cell membrane and form lipid bilayers. With the larger amount of unsaturated fatty acids, the phospholipids are more prone to rapid lipid oxidation because of the presents of more double bonds than saturated fatty acids with no double bonds. The increase in lipid oxidation from these compounds can cause negative off flavors such as warmed-over flavors which can be present in cooked samples that are reheated or old. This also causes them to be the primary source of lipid volatiles during cooking. Still, they may also provide lipid oxidation products during the initial cooking of meat which contribute to desirable aromas (Mottram, 1998). Products of lipid oxidation, either from the lipid fraction or from phospholipids, have also been shown to react with Maillard reaction products. These reactions can occur during cooking or during storage.

Lipids may contribute to the desirable flavor of cooked meat in several ways; they undergo thermal and oxidative change producing compounds which can contribute to meat aroma, but which may also react with components from the lean tissue to give other flavor compounds; they may also act as a solvent for aroma compounds accumulated during production, processing and cooking of meat (Mottram and Edwards, 1983). Thermal degradation of lipids greatly influences the development of beef flavor, producing over half of the volatiles reported in meat flavor (Mottram, 1998). Although lipid oxidation leads to formation of compounds which are responsible for flavor, at the same time it has unfavorable effects both on the nutritional value and some organoleptic features, particularly on meat color (due to the oxidation of bright red oxymyoglobin to dark red metmyoglobin; Summo et al., 2005).

Beef Species Flavor

Meat flavor is created by compounds that are derived from either lean or fat tissues and can be divided into two categories – the characteristic meat flavor common to all species of animals and the specific flavor of beef, pork, lamb or other species (Myers et al., 2009). The meaty flavor characteristic of most red meats is associated with the lean portion of the meat. Studies have identified more than 60 compounds that contribute to the meaty aromatics (Shahidi, 1998). Hornstein and Crowe (1960) discovered that beef and pork have similar meaty flavors, hypothesizing that compounds within the lean portion interacted with amino acids, carbohydrates, and polypeptides to produce the flavor of cooked meat.

Species-specific flavors, however, have been traditionally associated with the fat tissue (Myers et al., 2009). This is evident as more than 650 fat volatiles are released in beef when heated (Shahidi, 1994). Hydrocarbons, alcohols, ketones, and aldehydes from lipid oxidation influence species-specific flavor (Mottram, 1998). Mottram also stated that phospholipids may also provide lipid oxidation products during the initial cooking of meat that contribute to desirable aromas. However, Myers (2010) indicated that the lean tissue in meat products may be the principle contributor to species-specific flavors. Myers (2010) showed that increasing fat content in beef samples did not increase beef flavor, and in fact, decreased metallic/serumy flavor that was previously shown to be associated with beef samples.

Maillard Reaction

The Maillard reaction, or nonenzymatic browning, was introduced by Louis Maillard in 1912 to help explain amine and carbonyl reactions. This reaction is complex and provides a number of compounds that contribute to flavor, off-flavor, aroma and odor. The primary flavors developed as a result of the Maillard reaction are sweet and bitter flavors (Hurrell, 1982; Mottram, 1993; Mottram and Whitfield, 1993). The importance and complexity of the Maillard reaction is revealed by the large number of different review articles published (Mottram, 1998).

In the general Maillard reaction, amino compounds condense with a carbonyl group of a reducing sugar. This produces gylcosylamine which is rearranged and dehydrated to form furfural, furanone derivatives, hydroxyketones, and dicarbonyl compounds. As the reaction progresses, the intermediates can react with other amines, amino acids, aldehydes, hydrogen sulfide, and ammonia (Hodgen, 2006). These compounds can then continue to react with amine and other amino acids to produce more flavor-contributing compounds (Mottram, 1998). The positive flavors produced as a result of the Maillard reaction are: savory, meaty, roasted, and sweet. Negative flavors resulting from the Maillard reaction are bitter, metallic, and boiled, although bitter can be considered a positive flavor as well.

Strecker degradation is the breakdown of amino acids and dicarbonyl compounds. To become aldehydes, the amino acids are decarboxylated and deaminated while the dicarbonyls become α-aminoketones or aminoalcohols. These aldehydes are condensed to aldols that form furans, pyrazines, pyrroles, oxazoles, thiazoles, and other heterocyclic odor molecules (Shahidi, 1998). The compounds formed by Strecker degradation are important as the reactive intermediates for the formation of many highly reactive odoriferous compounds that play important roles in meat flavor, such as pyrazines and aldehydes. The level of pyrazines formed is dependent on reactant conditions, such as moisture content, temperature, pH, and time (Shahidi, 1994). The three Maillard products: 2,3-dimethyl-pyrazine, 2,5-dimethyl-pyrazine, and trimethyl-pyrazine are positively affected by both time and temperature which would be characteristic of Maillard products (Kerth et al., 2015).

The sulfur containing amino acids can produce hydrogen sulfide and ammonia, which are some of the most pungent compounds generated during cooking (Mottram, 1998). Most researchers agree that sulfur compounds are the most important volatiles formed during meat cookery (Shahidi, 1994). Sulfur-compounds derived from cysteine seem to be particularly important for the characteristic aroma of meat (Mottram, 1998). The most important volatiles related to meat flavor are furanones, ketones, sulfur compounds (sulfides, thiophenes and thiazoles), pyrroles, and pyrazines (Bailey and Einig, 1989; Shahidi, 1998). Meat would indeed have an entirely different flavor in the absence of sulfur compounds. Large quantities of hydrogen sulfide are produced during the heating of meat (Shahidi, 1998). MacLeod (1986) listed 78 compounds as having meaty-like aromas; 65 were heterocyclic sulfur compounds; seven were aliphatic sulfur compounds; and six were non-sulfur heterocyclics. Twenty-five of these compounds have been identified in meat, and most could be formed from the Maillard reaction.

Muscle Comparison

As previously stated, muscles vary in tenderness based on location and use. Similarly, muscles also vary in flavor. In a study conducted by Shackelford et al. (1995), the *M. Longissimus lumborum* (LM) had greater beef intensity when compared to the *M. Biceps femoris* (BF) and the BF was beefier than the *M. Gluteus medius* (GM). This data also showed that the off-flavor intensity was equal in the BF and GM (Shackelford et al., 1995). Calkins and Hodgen (2007) compiled data from 10 studies and ranked muscles for flavor intensity to give a more in-depth look in a single chart.

Yancey et al. (2006) studied the effects of total iron, myoglobin, hemoglobin, and lipid oxidation of uncooked muscles on livery flavor development and volatiles of cooked beef steaks. In this study, livery flavor increased and beef flavor identification decreased in the GM as total iron increased. In the *Psoas major* (PM), livery flavor decreased, but beef flavor identification did not change as total iron increased. It was concluded that total iron may contribute to livery flavor in the GM muscle, but is not a good indicator of beef flavor attributes. Myoglobin was also the highest in the GM over the PM. The myoglobin content and meat pH also can affect flavor attributes, but their contribution has not been fully elucidated (Meisinger, 2006). Neely et al. (1998) studied the effects of cut (LM, GM, and *M. Adductor*; AD), USDA quality grade, and city on in-home consumer ratings. Overall, consumers preferred steaks from the LM, followed by steaks from the GM and, lastly the AD. As the AD is from the round and used for locomotion, it has been shown to be higher in connective tissue levels (Neely, 1998). Not surprisingly, the AD was ranked last in overall like as it is tougher and lacks flavor due to cooking method. Still, the reason moist heating is used to prepare cuts from the round and other high connective tissue cuts, is to increase tenderness as collagen melts best with moist heat.

Quality Grade

Quality grades are determined by evaluating a composite of marbling and maturity that affect the palatability of meat. Consumer palatability is predicted by USDA quality grades (Claborn et al., 2011). The two main factors involved with grading are maturity and marbling score. Maturity score is based on the animal's age and the final maturity score is based on a composition of lean and bone maturity. There are substantial differences in palatability when youthful beef is compared to mature beef (A vs E maturity; Smith et al., 1982). Beef from older animals is more intense in flavor than younger animals and their meat is tougher due to the increase in insoluble collagen linkages (Miller, 1994). Marbling refers to the amount and distribution of intramuscular fat within the *M. Longissimus dorsi* (LD) muscle at the 12th-13th rib interface. Beef cuts with high levels of marbling are expected to be more tender, juicy and flavorful than cuts with lower levels of marbling (Tatum, 2007). Research has shown that as marbling score increased from practically devoid to moderately abundant, flavor desirability increased linearly (McBee and Wiles, 1967; Smith et al., 1983). Smith et al. (1983) also concluded that marbling score indirectly assessed concentrations of flavor and aroma in beef. This means that carcasses with higher marbling scores should produce more beefy tasting meat. Smith et al. (1983) also found that a higher marbling score dramatically decreased the incidence of undesirable flavors. As the marbling score increased from practically devoid to moderately abundant, the undesirable ratings decreased from more than 55% to zero.

Based on maturity and marbling score, carcasses are segregated into one of the eight USDA quality grades: Prime, Choice, Select, Standard, Commercial, Utility, Cutter and Canner. The flavor of steaks in the Prime, Choice, and Select categories were rated significantly higher than steaks from the other USDA Quality Grades (Smith et al., 1987). It should be noted that Smith et al. (1987) measured beef intensity for the overall flavor in beef as the whole muscle beef lexicon was not yet developed. Similarly, in a study comparing slaughter plant location, USDA quality grade, external fat thickness, and aging time effects on sensory characteristics of beef loin strip steak; it was found that Choice steaks had higher flavor intensity ratings than the Select steaks (Miller et al., 1997). Marbling, which is a key determinant of quality grade, had a large impact on beef flavor. As the amount of marbling or intramuscular fat increased, the amount of fat flavor increased (Miller, 2001). When fat content was less than 3%, palatability declined below an acceptable level. High fat content also can be associated with a negative perception of quality. As fat content exceeds 7.3%, issues related to increased consumption of fat and the relation of fat intake to coronary heart disease, obesity or some forms of cancer affect consumers' perception of acceptability (Miller, 2001; Savell and Cross, 1988).

pH

Many compounds that contribute to beef flavor are water-soluble. As pH increases in meat, the proteins have increased water binding properties. During cooking few water-soluble proteins are lost from high pH meat since there is less cooking loss (Miller, 2001). High pH (pH $\geq$ 6.0), or dark, firm, and dry (DFD) beef, is a result of long-term stress (poor handling, fatigue, extreme weather conditions, etc.) before harvest. Dark cutters, DFD beef, result from pre-slaughter stress, which depletes muscle glycogen. If glycogen is depleted by chronic long-term stress before slaughter then less lactic acid is formed and the meat does not acidify normally, hence, the ultimate pH remains high (Viljoen et al., 2002). Due to the lack of circulating blood in the muscle post-mortem, no waste (lactic acid) is disposed of. This causes lactic acid to build up in normal muscle causing pH drop. In DFD meat, due to the depletion of glycogen pre-harvest, there is no glycogen left to metabolize. This means less lactic acid build up and a lower pH drop in DFD meat. The meat is darker red to purplish in color as a result of less total light being reflected due to the light-absorptive properties of the muscle (Aberle, 2001).

Dark cutting beef is unattractive because of its dark red color; it is discriminated against by the consumer and therefore has been a problem to the beef industry for many years, particularly when the consumer can exercise a choice at purchase based on visual preference (Viljoen et al., 2002). Beef characterized as DFD is said to have a musty/moldy, very high beef flavor intensity, cowy/grassy, or bloody/serumy aromatic flavors (Calkins, 2007). The addition of sodium phosphates increases meat pH and if too high of levels of sodium phosphates are used, off-flavors similar to those reported for DFD beef can be found (Miller, 2001). Viljoen et al. (2002) found twice as many panelists preferred the appearance of raw meat with normal pH compared to raw DFD steaks because of the more attractive red color, compared to the dark color of raw DFD steaks. However, no significant differences were found between the hedonic ratings of the sensory attributes of fried normal and fried DFD steaks. Mottram and Edwards (1983) studied the effect of pH on the formation of volatile compounds in meat-related model systems and determined that the color, overall aroma and the nature of the volatile compounds were influenced by pH. From a flavor chemistry perspective, more nitrogen-containing compounds were detected at higher pH levels.

Degree of Doneness

Raw meat has been described as weak, salty, and blood-like and the desirable characteristic beefy flavors evolve as the degree of doneness increases (Crocker, 1948). The temperature of the heating element and the method of cooking affect the rate of cooking (Crocker, 1948). Aromatic compounds that are described as roasted, nutty, or fruity are developed from browning the surface of the steak as a result of cooking at high skillet surface temperatures (232ºC) or for long periods of time as would be found when cooking thick steaks (3.8 cm; Kerth et al., 2015). Cooking temperatures can impact the formation of these aromatic compounds as production of more aromatic compounds is achieved with longer cook times and higher temperatures. Bowers et al. (1987) found that internal end point temperature changes between 60-65°C and 80-85°C were determined to cause the biggest changes to flavor. Positive beef flavor attributes increased significantly at these two temperatures while bloody/serumy, metallic, and sourness decreased. Internal endpoint cook temperatures increased the cooked beefy/brothy, cowy/grainy, and carboardy aromas as well as liver-like aromatic. Cooked beef fat was not affected by end point temperature, but bloody/serumy, painty, and soured aromatics were always higher at lower temperatures (Belk et al., 1993). Calkins and Hodgen (2007) reported that varying cooking methods and internal temperatures yielded different flavors ranging from relatively bland to strong meaty notes, some with a high grill-like flavor, and others were distinctly roasted. As degree of doneness increased, serumy/bloody, metallic, sour, and bitter notes decreased while liver-like and cooked beef/brothy increased (Miller, 2001).

Gas Chromatography with Mass Spectrometry

The GC/MS systems have been the technique of choice for measurement of instrumental flavor and aroma analyses for nearly four decades (Shahidi, 1994). The GC reigns as the optimal method of separating volatile flavors and aromas into compounds, while the MS is the most powerful technique to identify unknown compounds (Shahidi, 1994). This technique is widely accepted and routine in flavor studies of muscle foods (Shahidi, 1994). In recent years, flavor research has become more common with the addition of an olfactometry port connected to a gas chromatograph (GC-O) device for smelling compounds after they are separated from each other.

The GC is used for separation and detection of volatile compounds, and it is also very helpful with identifying flavor compounds. The GC and MS technologies are capable of detecting hundreds of volatile compounds within one sample, however not all of the compounds collected are aromatic. By adding the GC-O, aroma-active components can be identified by a trained panelist, as the aroma-active components flow through the column, and the panelist can record the smell as it comes through, which creates an aromagram. As an aromagram is being recorded, a chromatogram is also recorded. Aromagrams and chromatograms can be compared to match the odors with chemical peaks. In GC-O, the volatiles are separated by the GC column then transported to the olfactory port, where they are combined with humidified air (Shahidi, 1994). Only small fractions of a large number of volatiles occurring in food actually contribute to odor and aroma (Mottram, 1998).

An increase in the popularity of flavor research has been spurred by advancements in GC-O technology. One aspect of the GC-O technology is that individual compounds have different odor thresholds, or the human detects them at different concentrations (Shahidi, 1994) The GC-O technology can also be used to identify these different odor thresholds of flavor compounds. During cooking, the lipids are degraded giving various derivative compounds that are aromatic, but these compounds traditionally have much higher aroma thresholds (higher concentrations are required to detect an aroma) compared to Maillard reaction products (MRP; Mottram, 1998). Aromas can occur at very low concentration and have sensory relevance due to low threshold values. While many of the peaks are very small and small changes are seen, it is important to remember that because many of the MRP have extremely low odor detection thresholds; even small changes in type and quantity are very important (Kerth, 2015).

GC-O technology is greatly beneficial in identifying flavor compounds and aroma profiles in meat. Once data is collected, it can then be correlated with other data like trained panel flavor ratings and consumer liking to find positive and negative flavors and compounds associated with each. This can help the beef industry reach out to more consumers and produce a product with the best flavors. As more information about the likes and dislikes of consumers with differing backgrounds and desires is understood, it will be possible to give specific cutting and cookery instructions to generate volatile aromatic compounds that match those consumer likes (Kerth, 2013).

Tenderness

Tenderness is considered by some the most important factor influencing consumer satisfaction for beef palatability (Savell et al., 1989). Tenderness in beef may be defined as the state of being easily comminuted or masticated (Ramsbottom and Strandine, 1948). Miller et al. (1995) found that consumers in home or restaurant settings could differentiate among steaks varying in Warner-Bratzler shear force values.

It is because of this that tenderness has been studied heavily and effects of tenderness have been researched (Koohmaraie, 1992; Shackelford et al., 1997).

Over the years, the following variables have been proposed to influence meat tenderness: animal age and gender; rate of glycolysis; amount and solubility of collagen; sarcomere length; ionic strength; and degradation of myofibrillar proteins (Koohmaraie, 1992). There are certainly many factors contributing to beef tenderness and not all the variation in tenderness is accounted for. Marbling has a large impact on tenderness but also is not definite when predicting tenderness (Carpenter et al., 1974; Goll et al., 1965; Smith et al., 1969). Four marbling theories exist that explain marbling's effect on meat tenderness (Carpenter et al., 1974; Savell and Cross, 1988). In the bulk density theory, it is theorized that fat is less dense than the lean tissue causing softer pockets, therefore the more marbling or adipose tissue deposited in the lean the easier the beef will be to bite through. The lubrication theory suggests fat being melted during heating causes a lubrication effect around the fiber making it easier to bite through. The insulation theory states the more fat in the lean, the more protection from heat shock of the fiber during cooking. Lastly the strain theory believes adipose tissue deposited in the lean develops with in the perimysium breaking the tissue making the meat more tender. More recently, the contribution of muscle fiber degradation post-mortem has been examined (Boehm et al., 1998; Dransfield et al., 1993; Koohmaraie, 1992; Koohmaraie, 1996; Olson et al., 1976; Taylor et al., 1995; Wheeler et al., 2000). The calpain system is also a large contributor to meat tenderness. Post-mortem tenderization is caused by enzymatic degradation of key myofibrillar and associated proteins (Koohmaraie, 1996). The improvement in meat tenderness during postmortem storage of carcasses at refrigerated temperatures has been known since the turn of the century, but the mechanism through which these changes are brought about has remained elusive and controversial (Koohmaraie, 1992). Aging of meat is an important step in the production of beef to improve tenderness. Postmortem, the structure of muscle is broken down increasing tenderness. Calpains, m-calpain and μ-calpain, are the enzymes that weaken the z disks as they assist in breaking down the structural proteins of the muscle fiber like titin, desmin, and nebulin. Current data indicates that calpains, more specifically μ-calpain, are most likely the only proteases that are directly involved in the events leading to meat tenderization (Koohmaraie, 1996). Calpain activity in living cells is almost certainly regulated by Ca^{2+} and by calpastatin, the protein inhibitor specific for the calpains (Koohmaraie, 1992). Under normal postmortem conditions, m-calpain is remarkably stable, whereas there is a gradual decline in the activities of μ-calpain, and calpastatin loses its activity rapidly. Both μ- and m-calpain undergo autolysis in the presence of sufficient calcium with the eventual loss of activity (Koohmaraie, 1992). Autolysis in the presence of higher free calcium concentration may be the reason why μ-calpain decreases in activity postmortem.

Connective tissue is a contributing factor to toughness of meat. In a study done by Cross et al. (1973), percent soluble collagen was significantly related to the contribution of connective tissue to toughness, as assessed by a sensory panel. Collagen is an abundant connective tissue protein and is a contributing factor to variation in meat tenderness and texture. It is the most abundant protein within the beef carcass. Collagen molecules are bound together through intermolecular crosslinks that help provide structure and strength (Weston et al., 2002). During collagen synthesis, aldimine-type bonds form between tropocollagen molecules providing reducible, heat-liable crosslinks which contribute to the organization and structural stability of collagen fibers (Light and Bailey, 1979). The proportion of these reducible intermolecular crosslinks (and heat-soluble collagen) in bovine muscle tissue has been shown to increase from the fetal stage to a maximum at about 12-18 months of age (Miller et al., 1983; Shimokomaki et al., 1972). During subsequent maturation, the crosslinks gradually stabilize to an insoluble, heat-resistant form, causing a reduction in the amount of intramuscular collagen that may be solubilized during subsequent cooking (Hill, 1966). This age-dependent strengthening of bonds and concurrent reduction in collage solubility provides the basis for the widely accepted maturity-beef tenderness relationship (Miller et al., 1983). A study done by Herring et al. (1967) also showed collagen solubility decrease significantly with each advancing maturity group in both LD and semimembranosus muscles. They also found that collage solubility was higher in the LD than the semimembranosus muscles. This decrease in percent soluble collagen is the reason cattle are harvested at a young age in the United States. Collagen solubility is also affected by the type of nutrition the cattle are being fed. A study done by Aberle et al. (1981) associated increased collagen solubility with the feeding of high-energy diets to youthful cattle. Collagen also plays a big role in cooked meat, as collagen fibers are heated during cooking they shrink. This shrinking of collagen fibers results in water loss and tougher meat due to the compression of the meat structure (Weston et al., 2002).

The gender of the bovine can cause differences in tenderness as well. Bulls tend to have more type III collagen with is much more heat stable. Burson et al. (1986) reported that LM of Simmental steers contained more heat soluble collagen than those from bulls, resulting in steaks from steers that were rated more tender. This shows the effects of testosterone on collagen maturation and how solubility decreases with increased testosterone.

Tenderness differs among muscles from various anatomical locations because of the variation in the traits or factors responsible for tenderness (myofibrillar or connective tissue; Cross et al., 1973). Muscles with higher use, such as locomotive muscles, have higher amounts of connective tissue then lower use muscles, such as support muscles like the psoas major. These muscles not only differ in amount of collagen, but also in the percentage of soluble collagen. The variation between these two types of samples makes sense as muscles with higher use levels need more structure and strength. In a study characterizing beef muscles, it was found that *Cutaneous omo-brachialis* had the highest collagen content of all the muscles studied (Seggern et al., 2005). This result may be explained by the muscles' location and function in the beef carcass. In the same study, the LD had the lowest collagen content (Seggern et al., 2005). Brooks and Savell (2004) reported that perimysial thickness in bovine semitendinosus muscle is on average 2 to 4 times thicker than in psoas major from the same animal. The expression of connective tissue within muscle is amazingly variable, depending on developmental stage, muscle position/function, animal breed, nutrition, exercise and injury (Purslow, 2005).

Conclusion

Based on previous research, it is obvious that palatability of beef is a very complex subject with several factors. Many factors have been studied thoroughly over the decades by excellent scientists in the meat industry and one main factor has been shown as important to the beef industry. As previously stated beef flavor is very complex, but is very important to the beef industry. Recent research studied the importance of beef flavor and consumer perception of heavy beef eaters (Glascock, 2014). Glascock (2014) found that different aromatic volatiles are characteristic of various beef lexicon attributes, and different flavors identified in the beef lexicon can be manipulated by muscle, quality grade, pH level, cooking method and final internal temperature endpoint. Further research on light beef eaters, in conjunction with Glascock (2014), could be used to improve the overall flavor of beef presented to consumers for products not acceptable in flavor.

CHAPTER III

MATERIALS AND METHODS

Sample Selection and Preparation

Beef subprimals: Choice top loins (IMPS 175), high pH (pH ≥ 6.0) top loins (IMPS 175), Select top sirloin butts (IMPS 181A), Choice tenderloins (IMPS 190A), Select bottom rounds (IMPS 171B), and Choice bottom rounds (IMPS 171B) were obtained from 10 beef carcasses (2 per carcass) on one selection day at Sam Kane Beef Processors in Corpus Christi, TX. These cuts were selected to differ in flavor based on previous research (Miller et al., 2012 and Glascock, 2014). Subprimals were cut into steaks (Choice strip loin, Select top sirloin butt, Choice tenderloin, and high pH top loin; 2.54 cm thick with no more than 0.25 cm external fat) or roasts (Select and Choice bottom rounds; 1.36 kg) anterior to posterior and randomly assigned to analysis so that one steak or roast was assigned to trained descriptive sensory evaluation, three steaks or roasts to each consumer city evaluation, one steak or roast to Warner-Bratzler shear force, and one to chemical evaluation. Roasts that were prepared for trained descriptive sensory evaluation were also used for Warner-Bratzler shear force. Steaks and roasts were vacuum-packaged, frozen and stored at -40°C until evaluated. Steaks and roasts were thawed for 24 hours and then cooked to 58 or 80 °C to induce differences in degree of doneness, bloody/serumy, liver-like, beefy, and brown/roasted flavor aromatics, and Maillard reaction products. These degrees of doneness and Quality Grade/cut differences also were used to affect the level of umami, fat-like, and metallic flavor attributes. To further induce differences in beef flavor attributes, steaks were cooked within temperature endpoint using different cooking methods to induce differences in Maillard reaction products and heat-induced lipid oxidation. Steaks were cooked either on a George Foreman Precision clamshell Grill-Model GRP99 (George Foreman/Applica Consumer Products Inc., Miramar, FL) set at 191 °C or a flat top grill at 232 °C. Roasts were cooked in a slow cooker (Crock-Pot Manual Slow Cooker, oval 5.67 liters) on the high setting. Internal temperatures were monitored by iron-constantan thermocouples (Omega Engineering, Stanford, CT) inserted into the steak or roast geometric center. Temperatures were displayed using an Omega HH501BT Type T thermometer.

This design resulted in 20 flavor treatments within a carcass. Each treatment within a cut and carcass was prepared for expert, trained descriptive attribute flavor evaluation; consumer sensory evaluation in State College PA, Portland OR, and Olathe KS; cooked chemical flavor volatile analysis; Warner-Bratzler shear force; raw chemical fat/moisture, pH, non-heme iron, myoglobin, and fatty acid analyses.

Expert, Trained Descriptive Beef Flavor Analyses

Steaks and roasts were evaluated by a trained beef flavor descriptive attribute panel that helped develop and validate the beef lexicon (Adhikari et al., 2011) and were also used in the previous study with moderate to heavy beef eaters (Glascock, 2014). This panel was retrained using the beef lexicon for 14 d. Beef flavor attributes were measured using the beef lexicon (0 = none and 15 = extremely intense) defined in Table 1. After training was complete, panelists were presented 12 samples per day, divided into two sessions ten min apart. After cooking, samples were placed in a food warmer set at 60°C (Alto-Shaam, Model 750-TH-II, Milwaukee, WI) for no longer than 20 min, and then cut into 1.27 cm cubes. Two cubes per sample were served in clear, plastic soufflé cups tested to assure that they did not impart flavors on the samples. Samples were identified with random three-digit codes and served in random order. Samples were cut and served immediately to assure samples were approximately 60°C upon time of serving (AMSA, 1995). Prior to the start of each trained panel evaluation day, panelists were calibrated using one orientation or "warm-up" sample that was evaluated and discussed orally. After evaluation of the orientation sample, panelists were served the first sample of the session and asked to individually rate the sample for each beef flavor lexicon attribute. Double-distilled water, unsalted saltine crackers and ricotta cheese were available for cleansing the palette between samples. During evaluation, panelists were seated in individual breadbox-style booths separated from the preparation area and samples were evaluated under red lights. In order to prevent taste fatigue, each evaluation day was divided into two sessions, with a ten-minute break between sessions and samples were served four minutes apart.

Consumer Evaluation

Consumers (n = 80 per city) were randomly selected in three cities (Olathe, KS; State College, PA; and Portland, OR) so that geographical areas represented the Midwest, the east coast and the west coast. In each city, four consumer sessions with approximately 20 consumers per session were conducted. After completion of each consumer session, four to five consumers (n = 16-20 consumers per city) were asked to participate in one-on-one interviews to determine attitudes toward beef and beef flavor.

Consumer panelists were recruited by the individual research institution in each city and all panelists were required to pass a consumer screener guaranteeing them to be over 18 years of age, have no food allergies, and consume beef a maximum of one or two times per week (including ground beef). Consumers were defined as light beef eaters for this study. On the day of evaluation, recruited consumer panelists were asked to sign an informed consent document. An instructional document, demographic ballot and ten individual sample ballots were provided to the consumer upon entering the testing room. Consumer demographics for age, sex, income, household size, type of employment, dietary restrictions, protein sources consumed, meat consumption levels of beef, and meat shopping habits were determined (Appendix 1). The ballot included overall, overall flavor, beefy flavor, grilled flavor, juiciness and tenderness liking using end- and middle-anchored 9-point hedonic scales (Appendix 2). Two open-ended questions were asked; consumers were asked to describe any positive or good flavors and any negative or bad flavors within each sample. Panelists were provided ten pre-identified random samples in a pre-determined random order four minutes apart. Samples were served in clear plastic soufflé cups labeled with a random three-digit number corresponding to their ballot. Samples were cut and prepared as defined for expert, trained beef flavor descriptive analysis.

Cooked Beef Volatile Flavor Evaluation

Volatiles were captured from the same steaks or roasts evaluated by the consumer panelists in Olathe, KS. After samples were prepared for consumers, approximately 35g of 1.27 cm beef cubes were placed in foil with a tag separated from the meat samples. Samples were placed in liquid nitrogen and frozen to -196°C. Samples were stored at -80°C until volatile analysis. Samples were placed in heated glass jars (473 mL) with a Teflon lid under the metal screw-top to avoid off-aromas and then set in a water bath at 60°C, where the headspace was collected with a solid-phase micro-extraction (SPME) Portable Field Sampler (Supelco 504831, 75 μm carboxen/ polydimethylsiloxane, Sigma-Aldrich, St. Louis, Mo). The headspace above each meat sample in the glass jar was collected for 2 h for each sample after the sample thawed and reached 60°C (about 1 h). Upon completion of collection, the SPME was injected in the injection port of the GC/MS, where the volatiles were desorbed at 280°C. The sample was then loaded onto the multi-dimensional gas chromatograph (GC/Agilent Technologies 7920 series GC, Santa Clara, CA) into the first column (30m X 0.53 μm ID/ BPX5 [5% Phenyl Polysilphenylene-siloxane] X 0.5 μm, SGE Analytical Sciences, Austin, TX). The temperature started at 40°C and increased at a rate of 7°C/minute until reaching 260°C. Upon passing through the first column the compounds passed to the second column {(30m X 0.53mm ID; BP20- Polyethylene Glycol) X 0.50 μm, SGE Analytical Sciences, Austin, TX}. The gas chromatography column then split into three different columns at a three-way valve with one going to the mass spectrometer (Agilent Technologies 5975 Series MSD, Santa Clara, CA) and two going to the two humidified sniff ports, which were heated to a temperature of 115° C, with glass nose pieces. The sniff ports and software for determining flavor and aroma were a part of the AromaTrax program (MicroAnalytics-Aromatrax, Round Rock, Tx). Panelists were trained to accurately use the Aromatrax software and they had also been trained according to the beef lexicon aromas.

Warner-Bratzler Shear Force

Steaks and roasts for Warner-Bratzler shear force (WBSF) were cooked in the same manner and at the same time as trained descriptive beef flavor analysis steaks. Cooking yield percentages were determine from weights recorded before and after cooking, and total cooking time was recorded for individual steaks. Steaks were trimmed of visible connective tissue to expose muscle fiber orientation. Six 1.3 cm diameter round cores were removed from each muscle. Cores were removed parallel to the muscle fibers and sheared once, perpendicular to the muscle fibers, on a United Testing machine (United SSTM-500, Huntington Beach, CA) at a cross-head speed of 200 mm/min using an 500 g load cell, and a 1.02 cm thick V-shape blade with a 60° angle and a half-round peak. The peak force (kg) needed to shear each core was recorded, converted to Newtons (N), and the mean peak shear force of the cores was used for statistical analysis. Values were converted using the following equation: WBS force (N) = WBS force (kg) × 9.81.

Raw Chemical Analyses

Raw meat pH, fatty acid composition, myoglobin content, and non-heme iron content were determined from each raw muscle (Choice strip loin, Select top sirloin butt, Choice tenderloins, high pH strip loin, Choice bottom round, and Select bottom round) within carcass. The pH was determined in duplicate (pH meter calibrated daily with 4.0 and 7.0 pH buffer solutions; IQ Scientific Instrument, Model IQ150, IQ Scientific Instrument, Inc., Carlsbad, CA, U.S.A.) by inserting the probe in two random locations within the anterior face of each subprimal.

Fatty acid methyl esters (FAME) were prepared from the lipid extracts as described by Morrison and Smith (1964). Approximately 3-5 g of ground beef was combined with 1 mL of 0.5 KOH in MeOH and heated at 70 °C for 10 min. After cooling, 1 mL of boron trifluoride (BF_3; 14%, wt/vol) was added to each sample, which was flushed with N_2, loosely capped, and heated at 70 °C for 30 min. The samples were removed from the bath, allowed to cool to room temperature, and 2 mL of HPLC grade hexane and 2 mL of saturated NaCl were added to the samples and vortexed. After phase separation, the upper phase was transferred to a tube containing 800 mg of Na_2SO_4 to remove moisture from the sample. An additional 2 mL of hexane was added to the tube with the saturated NaCl and vortexed again. The upper layer was transferred into the tube containing the Na_2SO_4. The hexane extract was transferred to glass scintillation vials. Each sample was evaporated to dryness at 60 °C under N_2 gas, subsequently reconstituted with HPLC grade hexane, and analyzed using a Varian gas chromatograph (model CP-3800 fixed with a CP-8200 auto- sampler, Varian Inc., Walnut Creek, CA; Chung et al., 2006). Separation of FAME was accomplished on a fused silica capillary column CP-Sil88 (100 m x 0.25 mm (i.d.); Chrompack Inc., Middleburg, The Netherlands), with helium as the carrier gas (flow rate = 1.2 mL/min). After 32 min at 180 °C, oven temperature was increased at 20 °C/min to 225 °C and held for 13.75 min. Total run time was 48 min. Injector and detector temperatures were at 270 °C and 300 °C, respectively. Standards from Nu-Check Prep, Inc. (Elysian, MN) were used for identification of individual FAME. Individual FAME were quantified as a percentage of total FAME analyzed. All fatty acids normally occurring in beef lean and fat trim, including isomers of conjugated linoleic acid, were identified by this procedure.

Myoglobin concentration was conducted according to Ricksand and Henrickson (1967) with modification to be read using a 96-well plate reader. Duplicate 25g samples were blended with 100 mL of double distilled H_20 for 3 min and centrifuged at 2000 x *g* at 6°C for 15 min. The supernatant was filtered through Whatman No. 3 filter paper and brought to volume in a 200 mL volumetric flask. From this 200 mL portion, duplicate 5 mL portions were taken and adjusted to pH of 7.1 using 0.5M phosphate buffer. Then, 1.25 mL of saturated lead acetate was added to the tube and centrifuged at 2000 x *g* for 15 min. Finally, 2.5 mL of the supernatant was combined with a mixture of mono- and di-basic phosphate to bring the phosphate concentration to 3M and the pH to 6.6. and was again centrifuged at 2000 x *g* for 15 min. One milliliter of the supernatant was combined with 0.7 mL of potassium ferricyanide and 0.7 mL of potassium cyanide to convert all forms of myoglobin to cyanmetmyoglobin. The samples were again centrifuged at 2000 x *g* for 15 min to ensure that all myoglobin had been transformed, and 200 µL were pipetted in triplicate on a 96 well plate and read at 520 nm on a plate reader (BioTek, Epoch, Winooski, VT).

For non-heme iron, samples were prepared following the procedures described by Rhee and Ziprin (1987) and read at 540 nm using a Cary 100 Varian UV/Visual Spectrophotometer (Varian Instruments, Sugarland, TX). To determine total non-heme iron, final absorbance of each sample was calculated by subtracting the absorbance of the incubated liquid phase with no color reagent added from the absorbance of the incubated liquid phase with color reagent added. Next, final concentration was calculated by subtracting the intercept of the standard curve from the final absorbance and dividing by the slope of the standard curve. Finally, non-heme iron was calculated as follows:

μg non-heme Fe/g meat = concentration (μg/mL) x ((15 + 0.2 + moisture in 5g meat))/5g x 1mL

Statistical Analyses

The trained panel descriptive flavor attributes and the volatile compounds were analyzed using analysis of variance, correlation coefficients, stepwise linear regression, and general linear models (version 9.3, SAS Institute, Cary, NC) to understand what chemical attributes drove specific beef flavor attributes. A predetermined α of (5%) was used in all analyses. For stepwise regression analyses, dependent variables were overall consumer liking and trained descriptive attributes of beef identity, brown/roasted, bloody/serumy, metallic, liver-like, and umami. Independent variables were volatile compounds defined using the AromaTrax and were allowed to enter the equation ($P \leq 0.05$). Final equations were presented and the intercept ß values and partial r^2 for each independent variable and final equation for r^2 were presented. For analysis of variance of chemical data, data were analyzed as a completely random design with treatment as a main effect. For trained panel, data were averaged across panelists after testing for panelist by treatment interactions to validate the panelists, and sensory day and order served were defined as random variables. For consumer data, city, treatment and their interaction were included as main effects and order served was defined as a random variable. For volatile category data, treatment was included as the main effect. Least squares means were calculated and the Fishers LSD function of SAS was used to determine differences between least squares means when significance was defined in analysis of variance table. Multivariate analysis was conducted using XLSTAT (v2013, Microsoft Corporation, Redmond, WA) where principal components analysis and partial least squares regression were used. Data were presented in bi-plots.

CHAPTER IV

RESULTS AND DISCUSSION

Trained Panel Flavor Attributes

The definition, reference standards, and intensities for expert, trained meat descriptive flavor aromatics, basic taste (Adhikari et al., 2011), juiciness and tenderness attributes (AMSA, 2015) are listed in Table 1. Descriptive sensory attributes were evaluated using 0-15 point scales.

Least squares means for beef flavor attributes across treatments are reported in Table 2. Beef identity, brown/roasted, bloody/serumy, fat-like, metallic, liver-like, umami, overall sweet, cardboard, burnt, and musty/moldy differed ($P \leq 0.05$) across treatments. Beef flavor attributes that were evaluated, but not present in any samples were green hay-like, sour aromatic, barnyard, rancid, heated oil, blue cheese, chemical, cumin, warmed over flavor, refrigerator stale, butter, soapy, sour milk dairy, chocolate, spoiled, dairy, medicinal, smoky wood, petroleum, painty and fishy. As flavor levels for these attributes were zero, data were not presented. Textural attributes of juiciness, muscle fiber tenderness, connective tissue amount, and overall tenderness also differed ($P \leq 0.05$) across treatments. Treatment affected beef flavor attributes as intended by the design. Beef identity was higher ($P \leq 0.05$) when steaks were cooked on the grill over other cooking methods. As degree of doneness increased, beef identity increased when steaks were cooked on the grill ($P \leq 0.05$). Beef identity was higher ($P \leq 0.05$) in Choice top loin steaks, Choice tenderloin steaks, and high pH top loin steaks cooked to 80 °C than the companion steaks cooked to 58 °C ($P \leq 0.05$). High pH top loin steaks had less beef identity than Choice top loin steaks when cooked to either internal temperature endpoint and with the grill cooking method ($P \leq 0.05$). Choice and select bottom round roasts cooked to 58 and 80°C did not differ ($P \leq 0.05$) in beef identity

Brown/roasted flavor tended to be lower and bloody/serumy flavor tended to be higher when steaks were cooked to lower internal temperature endpoints ($P \leq 0.05$) except for Choice tenderloin and Select top sirloin steaks cooked on the George Foreman. Bloody/serumy was higher in roasts cooked to lower internal temperature endpoints ($P \leq 0.05$). Fat-like flavor differed slightly across treatments with Select top sirloin steaks and Select and Choice bottom round roasts being the lowest in fat-like flavor. Metallic flavor was slightly lower in steaks and roasts cooked to higher degrees of doneness on the George Foreman grill and in the crockpot, except for Select top sirloin steaks ($P \leq 0.05$). Liver-like flavor was slightly detectable in steaks and roasts and grilled Choice tenderloin steaks, Choice top loin steaks, and Select top sirloin steaks were the lowest ($P \leq 0.05$) in liver-like flavor.

Umami flavor decreased in Choice bottom round roasts cooked from 58 to 80 °C ($P \leq 0.05$). Umami flavor did not differ ($P \geq 0.05$) in high pH top loin steaks, Select top sirloin steaks, or Select bottom round roasts regardless of cooking method or internal endpoint temperature. Sweet, sour, salty, bitter basic tastes, and overall sweet and cardboardy flavor attributes differed across treatments ($P \leq 0.05$). Musty/moldy flavor was barely detected and differed across treatments ($P \leq 0.05$). Burnt flavor was higher in grilled steaks, except high pH steaks, and steaks cooked to higher internal cooked temperature endpoint, except Choice tenderloin steaks ($P \leq 0.05$). Steaks cooked with the George Foreman grill and roasts had barely detectable or no burnt flavor, but did not differ. Warmed over flavor did not differ across treatments ($P \geq 0.05$).

As expected, juiciness decreased ($P \leq 0.05$) across all treatments as degree of doneness increased regardless of cooking method except for Choice tenderloin steaks, Choice bottom round roasts, and Choice top loin steaks cooked on the George Foreman ($P \geq 0.05$). Overall, steaks were juicer than roasts ($P \leq 0.05$). High pH top loin steaks and Choice top loin steaks cooked to a low degree of doneness were the juiciest ($P \leq 0.05$). Select top sirloin steaks cooked to a high degree of doneness were the driest ($P \leq 0.05$) steaks. Connective tissue amount differed slightly between cooking methods and degree of doneness, but Choice tenderloin steaks had the least amount of connective tissue and Choice and Select bottom round roasts had the highest amount of connective tissue, as expected ($P \leq 0.05$). Not surprisingly, bottom round roasts and Select top sirloin steaks were the toughest ($P \leq 0.05$). Choice bottom round roasts were slightly more tender than Select bottom round roasts ($P \leq 0.05$).

These results showed that muscle, cooking method, and internal temperature endpoint impacted beef flavor attributes as defined by the beef flavor lexicon, as well as texture attributes of juiciness, muscle fiber tenderness, connective tissue amount, and overall tenderness. These results were expected and compatible with the trained descriptive panel results and consumer panel results from recent beef flavor study conducted by Miller and Kerth (2012) and Glascock (2014). However, Miller and Kerth (2012) did not determine if these differences could be detected by consumers, and Glascock (2014) did not determine the impact on textural attributes such as juiciness, muscle fiber tenderness, connective tissue amount, and overall tenderness. Although Glascock (2014) did not determine the impact on textural attributes; Glascock concluded as degree of doneness increased, beef identity increased, and brown/roasted was lower and bloody/serumy was higher when steaks or roasts were cooked to lower internal temperature endpoints which was the same as the results from this study. Similarly, Belk et al. (1993) found increased endpoint cook temperatures increased the cooked beefy aromas as did Miller (2001). These results were similar to Shackelford et al. (1995), which found *M. Longissimus lumborum* (top loin) to be beefier than *M. Biceps femoris* (bottom round). However, Shackelford found the *M. Biceps femoris* to be beefier than the *M. Gluteus medius* (top sirloin). This difference could be due to the differences in cooking methods. Calkins (2007) concluded DFD beef to have a musty/moldy, very high beef flavor intensity, cowy/grassy, or bloody/serumy aromatic flavors. These results agreed with the findings of this study with bloody/serumy flavor higher in high pH steaks but beef identity differed to Calkins findings as it was lower in high pH steaks compared to normal pH top loin steaks.

Consumer Demographics

Consumer demographics (n = 239) are reported in Table 3. More than twice as many females participated than males. The age ranged from 20 or under (but over 18) to over 66, with almost 90% of consumers being between the ages 21-55. Consumer income were spread evenly across levels with 19.8% of consumers earning below $25,000 per year and 17.7% earning greater than $100,000 per year. The majority of consumers were in families of 4 or less and over two thirds of consumers were employed full time. A large majority of consumers ate chicken, beef, pork, and fish both in and away from home. Interestingly, 90% of participants consumed eggs away from home compared to 37.2% that ate eggs in home. Still a large portion of consumers also ate lamb and soy based products at and away from home. As designed, the majority of participants consumed beef two or less times per week and almost 93% of participants consumed beef three or fewer times per week. Purchasing habits indicated the majority of consumers did not purchase grass-fed, dry-aged, or organic beef. The primary classification of beef bought by consumers was traditional beef. Consumers mainly use grilling as a method to prepare beef and tend to eat a large variety of cuisines.

Consumer Perception of Beef Flavor

Table 4 shows consumer perceptions of steaks and roasts by treatment. Overall consumers liked Choice tenderloin steaks, Choice top loin steaks, Select top sirloin steaks, and high pH top loin steaks and did not like bottom round roasts cooked to a higher internal endpoint cook temperature ($P \leq 0.05$) as they were the lowest in overall like/dislike. Neely et al. (1998) also found consumers preferred top loin steaks over top sirloin steaks. In addition to differences in cut, it was expected that steaks with a USDA Choice quality grade would be liked more that steaks with a USDA Select quality grade. Smith et al. (1983) found that a higher marbling score dramatically decreased the incidence of undesirable flavors and Miller et al. (1997) found that Choice steaks had higher flavor intensity ratings than the Select steaks. Consumers tended to like beef cooked to lower internal endpoint temperatures on the grill compared to steaks cooked on the George Foreman grill, except consumers liked Choice tenderloin steaks and

Choice top loin steaks cooked on the grill to either internal endpoint cook temperature and liked high pH top loin steaks cooked to a higher internal endpoint cook temperature on the grill ($P \leq 0.05$). These results are not surprising as high pH meat tends to be higher in bloody/serumy and tends to takes more cooking to achieve the same level of protein denaturation as normal pH meat. Calkins (2007) found beef characterized as DFD is said to have a musty/moldy, very high beef flavor intensity, cowy/grassy, or bloody/serumy aromatic flavors. Miller (2001) concluded, during cooking few water-soluble proteins are lost from high pH meat since there is less cooking loss. Consumers tended to like beef that was grilled and disliked beef cooked in the crockpot ($P \leq 0.05$), however, consumers had similar liking ratings for Select top sirloin steaks cooked on the George Foreman grill to 58°C as Select top sirloin steaks cooked on the grill to higher internal cook temperature endpoint. This could be due to consumers preferring steaks cooked to a lower internal cook temperature endpoint. Research has shown top sirloin steaks are less tender and have more variation than top loin steaks (Harris et al., 1992; Morgan et al., 1991). Savell et al. (1999) found top sirloin steaks cooked with outdoor grilling and broiling methods, to well done or greater degrees of doneness, generally received among the lowest consumer palatability ratings. These results agreed with a similar study by Glascock (2014) who focused on heavy beef eaters. Glascock (2014) also found that consumers preferred steaks cooked to a lower degree of doneness. Also, these results agreed with a nationwide, in-home beef palatability consumer study by Neely et al. (1998) and reported that regardless of quality grade or degree of doneness, steaks originating from the bottom round were the least preferred.

Flavor like/dislike and beef flavor like/dislike showed similar results ($P \geq 0.05$) to overall like/dislike ratings across treatments with Choice tenderloin, Choice top loin, and Select top sirloin cooked on the grill being liked the most ($P \leq 0.05$), and the bottom round roasts being liked the least ($P \leq 0.05$) for flavor like/dislike and beef flavor like/dislike. Consumers rated beef flavor higher ($P \leq 0.05$) when steaks were cooked on the grill compared to steaks cooked on the George Foreman grills. Beef flavor like/dislike and grill flavor like/dislike was higher ($P \leq 0.05$) for Choice tenderloin, high pH top loin, Select top sirloin, and Choice top loin steaks cooked using a grill than steaks cooked on a George Foreman grill ($P \leq 0.05$). Choice and Select bottom round roasts were lowest ($P \leq 0.05$) in beef flavor like/dislike except for high pH top loin steaks cooked on the George Foreman, and lowest for grilled flavor like/dislike ($P \leq 0.05$). High pH top loin steaks grilled and cooked to 80°C were rated higher ($P \leq 0.05$) for beef flavor intensity, grill flavor like/dislike, and grill flavor intensity. These results showed that consumers liked grilled beef flavor. However, Goodson et al. (2002) found clod steaks that were grilled received low ratings when prepared to medium- well and more degrees of doneness. Savell et al. (1999) found similar results showing top sirloin steaks cooked to well done or greater degrees of doneness with outdoor grilling method, tended to receive low ratings. It is important to note low ratings were seen in steaks with a higher internal cook temperature endpoint and consumers tend to like steaks prepared to lower internal cook temperature endpoints. These results are understandable as steaks cooked to higher degrees of doneness have to sit on the grill longer giving more possibility for burning. Cooking longer to obtain higher internal temperature endpoints results in more off-flavors associated with lipid oxidation and heat denaturation (Mottram, 1998). Lorenzen et al. (1999) determined that consumers cooked steaks on an outdoor grill most often. Glascock (2014) found similar results and reported that consumers preferred steaks cooked on a grill compared to a George Foreman grill or a meat cooked in a crockpot. Glascock (2014) also showed grilled flavor and beef flavor were related to overall liking.

As expected, juiciness liking was higher ($P \leq 0.05$) in steaks and roasts cooked to a lower internal temperature endpoint, especially for Select top sirloin steaks. Lorenzen et al. (1999) found a very clear decline in juiciness with higher degrees of doneness for steaks grilled outdoors and broiled steaks. Interestingly, Select top sirloin steaks cooked to a lower internal cooked temperature endpoint had a 3-point higher juiciness liking rating regardless of cooking method when compared to Select top sirloin steaks cooked to higher internal cook temperature endpoints. Savell et al. (1999) similarly found in top sirloin steaks, a 2-point difference in juiciness liking rating between well done or more steaks and medium rare or less steaks Tenderness liking results were similar to juiciness liking with consumers preferring steaks and roasts cooked to a lower internal temperature endpoint. Parrish et al. (1973) found as the internal temperature increased, the palatability characteristics for flavor, tenderness, juiciness and overall acceptability decreased, in a linear manner. Choice tenderloin steaks rated highest for both juiciness liking and tenderness liking. Similar results were seen from Shackelford et al. (1995) who found *Psoas major* to be more juicy and tender than *Longissimus*, *Gluteus medius*, and *Biceps femoris*. These results indicated that consumer beef flavor liking, tenderness liking, and juiciness liking were highly related to overall liking ratings and that differences in flavor impacted overall liking. Tenderness, flavor and juiciness, significantly increased by enhancement, were found to be the most important factors with respect to consumers eating satisfaction (Robbins et al., 2003).

Trained Descriptive Flavor Panel and Consumer Perception of Beef Flavor Interaction

The relationship between trained descriptive beef flavor attributes and consumer acceptance is reported in Table 5. This table shows that descriptive beef flavor attributes of beef identity, fat-like, and brown/roasted were moderately related to overall consumer liking ($P \leq 0.05$). It also showed that descriptive texture attributes of juiciness, muscle fiber tenderness, connective tissue amount, and overall tenderness were moderately related to overall consumer liking ($P \leq 0.05$). As these attributes increased, consumer like/dislike scores increased or consumers liked the beef to a greater extent. Umami, salty, cardboardy, burnt, and musty-earthy/humus were also slightly and positively related to consumer overall like/dislike ($P \leq 0.05$). Beef identity, brown/roasted, fat-like, juiciness, and connective tissue amount also had a moderate and umami, sweet, salty, overall sweet, burnt, muscle fiber tenderness, and overall tenderness had a slight positive relationships to flavor liking ($P \leq 0.05$). At the same time, musty-earthy/humus, cardboardy, sour aromatic, and liver-like had a slight negative relationship ($P \leq 0.05$) with overall flavor like. Therefore, as musty-earthy/humus, cardboardy, sour aromatics, and liver-like increased, flavor liking decreased. Beef identity and brown/roasted had a moderate relationship ($P \leq 0.05$), and fat-like, overall sweet, burnt, juiciness, muscle fiber tenderness, connective tissue amount, and overall tenderness had a slight positive relationship ($P \leq 0.05$) to beef flavor liking. Similar to flavor like, musty-earthy/humus, cardboardy, sour aromatics, and liver-like had negative relationships with beef flavor liking. For grilled flavor like, beef identity and brown/roasted were strongly related and fat-like, salty, and burnt were moderately related ($P \leq 0.05$). Negative relationships for grilled flavor liking included liver-like, sour, cardboard, sour aromatics, and musty-earthy/humus ($P \leq 0.05$). Bloody/serumy, fat-like, juiciness, muscle fiber tenderness, and overall tenderness had a moderate relationship with juiciness liking while Warner-Bratzler shear force had a moderate negative relationship ($P \leq 0.05$). For tenderness like, juiciness, muscle fiber tenderness, connective tissue amount, and overall tenderness had a strong relationship ($P \leq 0.05$) and fat-like had a moderate relationship ($P \leq 0.05$) to tenderness liking. Similar to juiciness liking, Warner-Bratzler shear force also had a moderately strong relationship to tenderness liking ($P \leq 0.05$). These results were expected as perceived tenderness has been shown to be impacted by marbling, muscle fiber tenderness, and connective tissue amount and solubility (Cross et al., 1973; Carpertner et al., 1974; Koohmaraie, 1996).

To understand how consumer attributes influenced overall consumer liking, linear regression equation including only consumer variables to predict overall consumer liking was reported in Table 6. Overall flavor liking, tenderness liking, beef flavor liking, juiciness liking, and grilled flavor liking accounted for 85% of the variation in overall consumer liking. This indicated that overall flavor liking, tenderness liking, beef flavor liking, juiciness liking, and grilled flavor were all related to overall consumer liking. This is slightly lower than similar results reported by Glascock (2014); however, tenderness attributes and juiciness attributes were not tested in that study. In a study done by Lorenzen et al. (2005), it was concluded that tenderness was not the only driving factor in consumer acceptance, but that flavor played an equally important role in overall consumer liking.

To further assess the relationship between all 20 treatments and consumer liking, principal component analysis was conducted (Figure 1). The principal components analysis biplot showed that Choice tenderloin steaks grilled to 58°C, Choice tenderloin steaks grilled to 80°C, Choice top loin steaks grilled to 58°C, and Select top sirloin steaks grilled to 58°C were closely clustered with consumer overall liking. Neely et al. (1998) showed strong, positive relationships between overall liking with tenderness, juiciness, and flavor desirability of top loin, top sirloin butt, and top round. Choice top loin steaks grilled to 80°C were closely related to both consumer flavor and beef flavor liking. Choice and Select bottom round roasts cooked in a crockpot to 80°C were in opposite quadrants to consumer tenderness and juiciness liking. Choice and Select bottom round roasts cooked in a crockpot to 58°C, and high pH top loin steaks cooked on a George Foreman grill to 58°C were clustered and in opposite quadrants to overall flavor, beef flavor, and grilled flavor liking. These results reinforce the findings in Table 4 that consumers preferred steaks cooked to a lower internal endpoint temperature on a grill and did not like roasts cooking in the crockpot. Glascock (2014) also found consumers liked steaks cooked on a grill to a lower internal endpoint temperature and disliked roasts cooked in a crockpot. Hunt et al. (2014) found the round showed the lowest percentage of acceptability for all palatability traits. Hunt also determined that

Choice *Gluteus medius* and *Longissimus lumborum* were considered "unsatisfactory" less often than any other muscle × quality grade combination, while *Semimembranosus* were rated as "unsatisfactory" more often than all other muscles.

Figure 2 shows the relationship between trained panel descriptors and consumer liking for all treatments. Juiciness, muscle fiber tenderness, connective tissue amount, overall tenderness, and fat-like were closely related to consumer juiciness, tenderness, and overall liking. Fat-like, sweet, overall sweet, and salty were very closely related to overall, flavor, grilled flavor, and beef flavor liking. Umami, beef identity, brown/roasted, and burnt were also related to overall, flavor, grilled flavor, and beef flavor liking. Liver-like, green hay-like, and sour clustered together and were opposite of umami, brown/roasted, burnt, and beef identity. These results indicated that as umami, brown/roasted, beef identity, and burnt increased, liver-like, green hay-like, and sour decreased. Liver-like segmented opposite of overall flavor, beef flavor, and grilled flavor liking. These results reinforced findings from Table 5, indicating that browned/roasted, beef identity, and grilled flavor and overall flavor drove overall consumer liking and liver-like flavor was not associated with consumer overall liking.

Cooking treatments influenced the flavors present. Fat-like closely clustered with the Choice top loin steaks cooked on the grill to 58 °C and tenderloin steaks grilled to 58°C. Tenderloin steaks and high pH top loin steaks cooked on the George Foreman grill to 58° clustered with metallic and bloody/serumy. The aforementioned clusters were most closely related to the consumer attributes. Opposite of overall liking were Choice and Select bottom round roasts cooked in a crock pot to 80 °C and these treatments segmented with warmed-over flavor, cardboardy, musty/moldy, and sour aromatic flavor attributes. High pH top loin steaks cooked on a George Foreman to 58 and 80°C were clustered closely with sour dairy. Choice top loin steaks grilled to 80°C clustered closely with umami, brown/roasted, beef identity, burnt, and grilled flavor liking. This means consumer liking can be influenced by the cut of the steak, the method it is prepared, and what internal temperature endpoint it is cooked to. To produce the most positive flavors and to have the highest consumer liking, Choice top loin steaks should be cooked on a grill to lower internal endpoint temperatures. Light beef eaters liking profile was similar to heavy beef eaters with fat like driving overall like and the price of beef negatively influencing the consumption of beef.

Raw Chemical Attributes

Chemical attributes were determined on raw steaks and roasts prior to cooking (Table 7 and 8). As expected, pH was highest for top loin steaks from carcasses that were selected for a pH of over 6.0 ($P \leq 0.05$). Select bottom round roasts were the highest and Choice top loin steaks were the lowest in moisture percentage ($P \leq 0.05$). As expected the inverse was seen in lipid percentage with Choice top loin steaks being the highest and Select bottom round roasts being the lowest ($P \leq 0.05$). This inverse relationship was seen further in Figure 3 where moisture (%) and lipid (%) were in opposite quadrants. Non-heme iron and myoglobin did not differ across treatments ($P \geq 0.05$). The fatty acids that differed ($P \leq 0.05$) across muscles were 16:0, 16:1, 18:0, 18:2, and 20:4 (Table 8). Choice tenderloin steaks had a greater ($P \leq 0.05$) amount of 16:0 fatty acids as compared to Choice top loin steaks, Select top sirloin, and Choice and

Select bottom round roasts. Choice bottom round roasts had the highest ($P \leq 0.05$) concentrations of 16:1 and Choice tenderloin steaks had the lowest ($P \leq 0.05$). Select bottom round roasts had the least amount and Select top sirloin steaks had the most ($P \leq 0.05$) of 18:0 fatty acids. Both Choice and Select bottom round roasts had higher ($P \leq 0.05$) amounts of 18:2 when compared to Choice and high pH top loin steaks. Similarly, Choice and high pH top loin steaks were lower ($P \leq 0.05$) in 20:4 fatty acids when compared to Choice bottom round roasts. Previous literature has also linked raw chemical data and fatty acid content to beef flavor (Calkins and Hodgen, 2007; Meisinger et al., 2006; Wood et al., 2004; Yancey et al., 2006). More recent research similar to this project has linked raw chemical data to beef flavor and consumer perception (Glascock, 2014). Cuts vary in chemical attributes and influence flavor ever prior to cooking. Positive flavor attributes can be maximized by utilizing the cuts with the best chemical attributes for positive flavors.

Table 9 shows the correlation coefficients between raw chemical data and trained descriptive sensory panel flavor attributes. Beef identity and brown/roasted flavor attributes were moderately correlated with lipid percentage and negatively correlated to moisture percentage ($P \leq 0.05$). Bloody/serumy was also moderately related to lipid percentage and negatively related to moisture percentage, but was also moderately related to fatty acid 18:2 ($P \leq 0.05$). Again the same correlations with lipid and moisture percentages for fat-like, but it is also had moderate negative relationships to fatty acids 18:2 and 20:4 ($P \leq 0.05$). Metallic was slightly correlated to fatty acid 18:0 and 18:2 with a slight negative relationship with lipid percent ($P \leq 0.05$). pH and liver-like flavor were slightly negatively related ($P \leq 0.05$). Umami flavor had a slight positive correlation with lipid percentage and slight negative correlation to moisture percentage ($P \leq 0.05$). Sweet basic taste too had slight positive correlations to lipid percentage and negatively to moisture percentage ($P \leq 0.05$) and also had a slight positive relationship to fatty acids 18:2 and 20:4 ($P \leq 0.05$). Sour had a moderate negative relationship to pH and salty had a slight negative relationship with 20:4 fatty acid but was also positively correlated to lipid percent and negatively correlated to moisture percent ($P \leq 0.05$). Bitter had a slight positive correlation with moisture percent and slight negative correlation with lipid percent, and was also had slight negative correlations with fatty acids 14:0 and 16:0 ($P \leq 0.05$). Overall sweet was also correlated negatively to lipid percent and positively with lipid percent, and slight negative correlations to fatty acids 18:2 and 20:4 ($P \leq 0.05$). Cardboardy was positively related to moisture percent, fatty acid 16:1, 18:2, and 20:4; and negatively correlated with lipid percent ($P \leq 0.05$). Warmed over flavor had slight negative correlations to myoglobin concentration and 16:0 fatty acid, and slight positive correlations to moisture percent and fatty acids 16:0 and 18:2 ($P \leq 0.05$). Sour aromatic had slight negative relationships with pH, and fatty acids 15:0, 17:1cis, 18:0, and 18:1 ($P \leq 0.05$). Sour dairy had slight negative relationships with fatty acids 16:1, 18:2, 20:4, and 24:0 ($P \leq 0.05$). Burnt was positively correlated with pH, non-heme iron, and lipid percent and also had a negative relationship with moisture percent ($P \leq 0.05$). Musty-earthy/humus had a positive relationship to moisture percent and a negative relationship to lipid percent ($P \leq 0.05$). Juiciness had moderate negative correlations to moisture percentage and fatty acid 18:2, and positive correlations to pH and lipid percentage ($P \leq 0.05$). Muscle fiber tenderness had negative correlations to moisture percent and fatty acid 20:4, but also a positive correlation to lipid percentage ($P \leq 0.05$). Connective tissue and overall tenderness had the same relationships as muscle fiber tenderness, but they had a moderate negative relationship to 22:6 fatty acid ($P \leq 0.05$).

The relationship between raw chemical data and consumer sensory attributes was displayed in Table 10. All consumer sensory attributes had a moderate negative relationship with moisture percentage and a moderate positive relationship with lipid percentage ($P \leq 0.05$). Overall liking had a moderate negative correlation with 20:4 ($P \leq 0.05$) and weaker negative correlations with fatty acids 16:1, 18:1, 18:2, and 24:0 ($P \leq 0.05$). Overall liking was positively correlated to non-heme iron, lipid percentage, and fatty acids 16:0, 17:1cis, and 18:0 ($P \leq 0.05$). Fatty acids 16:1, 18:2, and 20:4 had a moderate negative relationship with overall flavor liking ($P \leq 0.05$). Flavor liking also had moderate positive relationships to fatty acids 16:0 and 18:0 ($P \leq 0.05$). Beef flavor liking was positively correlated to non-heme iron concentration, fatty acids 16:0, 17:1cis, and 18:0, but also had negative correlations to fatty acids 16:1, 18:1, 18:2, 20:4, and 24:0 ($P \leq 0.05$). Grilled flavor liking had moderate, negative relationships with fatty acids 16:1, 18:2, and 20:4; and a positive correlation with 18:0 ($P \leq 0.05$). Juiciness was negatively correlated to fatty acids 16:1, 18:1, 18:2, and moderately related to 20:4. pH and fatty acids 14:0, 16:0, 18:0, and 20:5 were positively related to juiciness liking ($P \leq 0.05$). Tenderness liking was negatively correlated to fatty acids 16:1, 18:1, 18:2, and 20:4, but was positively correlated to fatty acids 14:0, 16:0, and 18:0 ($P \leq 0.05$).

Interestingly fatty acids 15:0 and 22:6 were not significantly correlated to any of the consumer sensory attributes ($P \leq 0.05$). Previous research on beef flavor also saw similar results with correlations between fatty acid 22:6 and consumer sensory attributes (Glascock, 2014). Yancey et al. (2006) found beef flavor decreased in the *Gluteus medius* as total iron increased as well, however it was concluded that total myoglobin concentration in the *Gluteus medius* muscle is not a good indicator of beef flavor attributes. Meisinger, (2006) stated the myoglobin content and meat pH also can affect flavor attributes, but their contribution has not been fully elucidated. Maughan et al. (2012) found meat with elevated pH got higher liking scores than the normal pH meat. However, these results showed no correlation with overall liking only a slight correlation with juiciness liking. This difference could be amplified because this study was done on beef and not pork like Maughan et al. (2012).

To understand drivers of consumer overall liking, two stepwise regression analyses were conducted and reported in Tables 11 and 13. The first analysis examined the relationship between raw chemical and fatty acid variables to predict consumer overall like/dislike (Table 11). Two variables were included in the equation with moisture percentage the first variable to enter the equation and it accounted for 37% of the variation in overall consumer liking. Chemical moisture content is related to juiciness, which can be used to predict consumer palatability. Therefore, it would be expected that chemical moisture content entered the equation for consumer overall liking first. Fatty acid 16:1 was the second variable to enter the equation and was the only fatty acid variable in the equation. The two variables accounted for 48% of the variation in overall consumer liking. Fatty acid content has been related to beef flavor (Mottram and Edwards, 1983). These data show a stronger relationship of fatty acids to overall consumer liking when used in combination with moisture percentage. Glascock (2014) found chemical lipid percentage was the first variable to enter the equation on the relationship between raw chemical and fatty acid variables to predict consumer overall liking. This difference could be because Glascock (2014) did not account for juiciness in consumer liking and concluded that while significant ($P \leq 0.05$), the equation was not strong and did not account for sufficient amount of variation to be used to predict consumer overall liking on a consistent basis.

Figure 3 showed the relationship between consumer sensory attributes, fatty acid content, and chemical data. All consumer sensory attributes clustered closely together suggesting that all attributes have a relationship with each other. Percentage of lipid, overall liking, flavor liking, beef flavor liking, grilled flavor liking, juiciness liking, and tenderness liking were clustered together indicating a relationship between these attributes. Myoglobin, non-heme iron, and fatty acid 18:0 were also slightly clustered with consumer sensory attributes. Interestingly, myoglobin and non-heme iron were clustered. This differed from findings of Meisinger et al. (2006) and Glascock (2014) who both found no strong correlation between myoglobin and non-heme iron. This difference could be because those studies did not include all of the cuts used in this study including the tenderloin. Yancey et al. (2006) found that livery flavor may be related to total iron content in the *Gluteus medius*, and to myoglobin concentration in the *Infraspinatus*, *Psoas major*, and *Gluteus medius* muscles. Moisture percentage was in an opposite quadrant than lipid percentage and consumer sensory attributes. This suggests there was a negative relationship between moisture percent and those attributes.

Figure 4 shows the relationship between trained beef flavor descriptive attributes, consumer overall liking, fatty acid content, and chemical data. Fat-like flavor, juiciness, juiciness liking, and lipid percentage all cluster indicating a relationship between these attributes. Non-heme iron, metallic, umami, and 15:0 were related. The relationship between non-heme iron and metallic flavor agree with research by Yancey et al. (2006) that suggested muscles with higher concentrations of myoglobin and heme iron typically exhibited liver-like and metallic flavors. Fatty acid 16:0 was the closest fatty acid clustered with beef flavor, overall, and overall flavor liking. Cardboardy clustered with 20:4 while 22:6 was clustered to moldy/musty and bitter flavor attributes. Brown roasted and beef identity clustered closely to grilled flavor, overall flavor, and overall and beef flavor liking. Most of the attributes that negatively impact beef flavor (liver-like, musty/moldy, cardboard, sour aromatic, sour, and bitter sensory attributes) were on opposite sides of the bi-plot. Strong relationships were seen with beef identity flavor and other attributes indicating that fatty acid, pH, non-heme iron and myoglobin did not strongly drive beef identity. This means consumers like beef that is grilled and has fat. Glascock (2014) found similar results with brown/roasted and beef identity clustering close to grilled flavor, over all flavor, and overall and beef flavor liking. Glascock (2014) also showed negative beef attributes clustered opposite of consumer sensory attributes. Bryhni et al. (2003) also found that metallic flavor, warmed over flavor, bitter, and sour odor all had negative influences on consumer liking.

Volatile Aromatic Flavor Components

Table 12 reported the volatile 248 aromatic compounds found by the GC/mass spec system and Kovats/Linear Retention indices, that were aroma events or panelists identified an odor at the sniff port when these compounds were eluting off the GC column. The mean area under the curve for each compound is reported. In our previous research, a different number of compounds were reported. This study included tenderloins that may have contributed to this effect where Glascock (2014) did not. To further understand the relationships between volatile flavor, consumer overall liking, and descriptive beef flavor attributes, principal component analyses were conducted (Figure 5). 2-ethyl-3,5-dimethyl pyrazine clustered with fat-like, overall sweet, sweet, flavor liking, and overall liking. This exhibits consumers liking for Maillard reaction as pyrazines are compounds formed from the Maillard reaction.

Regression equations were calculated to determine what specific chemical compounds could be used to predict consumer overall liking (Table 13). Forty-eight aromatic volatile chemicals accounted for 74% of consumer overall liking. While most of these volatile aromatic compounds accounted for 1 to 2% of the variation in overall consumer liking, they were significant (P|≤|0.15). Benzaldehyde (C18) was the first variable to enter the equation and accounted for 7% of the variation in overall consumer liking, followed by 2-acetylthiazole (C100) and accounted for 6% of the variation in overall consumer liking. Benzaldehyde is an organic compound consisting of a benzene ring with a formyl substituent. It is the simplest aromatic aldehyde and one of the most industrially useful. Benzaldehyde is the primary component of bitter almond oil and has a characteristic pleasant almond-like odor. 2-Acetylthiazole is a 5 carbon ring with an acetyl group. It has a nutty or roasted aroma. The third variable to enter the equation is 2-furancarboxaldehyde (C154) and accounted for 5% of the variation in overall consumer liking. These were followed by octadecanal (C325) and benzeneacetaldehyde (C25) which accounted for 3% and 4% of the overall consumer liking respectively. Octadecanal is a long-chain aldehyde. Aldehydes are formed from the Strecker reaction as part of the Maillard reaction. Benzeneacetaldehyde is a benzene ring with an aldehyde. Together these compounds accounted for about 25% of the total variation in the equation to predict overall liking. Trimethyl pyrazine only accounted for 1% of the variation in the equation to predict overall liking. Pyrazine compounds are a product of the Maillard reaction and are produced with high heat cookery. The production of these aroma compounds from the Maillard reaction prevent warmed over-flavor in beef (Parliament, 1989), thus increasing overall liking. It is not surprising that compounds responsible for roasted flavors entered the equation for overall liking as these descriptive flavor attributes were most closely clustered with overall liking in Figure 5. Compounds associated with Maillard reaction products, heat denaturation and lipid oxidation were included in the equation indicating that all three reactions are associated with consumer overall liking. The remaining compounds accounted for small amounts of variation and were a mixture of both Maillard reaction and lipid degradation products. This research coincided with original beef flavor research conducted by Batzer et al. (1960) that determined cooked meat flavor was the result of interactions between multiple compounds. These chemicals could be used to predict consumer acceptability for moderate to heavy beef-eaters.

Stepwise regression equations to predict descriptive sensory flavor attributes for beef identity, brown/roasted, bloody/serumy, fat-like, metallic, liver-like, and umami were calculated (Tables 14, 15, 16, 17, 18, 19, and 20 respectively). These equations used 32, 47, 30, 53, 39, 43 and 56 volatile aromatic compounds to account for 67, 81, 51, 77, 61, 61 and 82% of the variation in beef identity, brown/roasted, bloody/serumy, fat-like, metallic, liver-like, and umami, respectively. One single variable did not account for a large amount of variation for any of the specific flavor compounds and as previously stated compounds associated with Maillard reaction products, heat denaturation and lipid oxidation were included in each equation.

No single compound accounted for a high amount of variation in beef flavor identity (Table 14). 3-methyl-butanal (C2) was the first variable to enter the equation and accounted for 11% of the variation in beef flavor identity. It is a small organic compound that has a malty aroma. The next to enter the equation was 2-ethyl-3,5-dimethyl- pyrazine (C22) and it accounted for 6% of the variation in beef identity. Although pyrazine compounds were not closely clustered with beef identity or overall liking, 2-ethyl-3,5-dimethyl-pyrazine was the single compound most closely clustered with overall consumer liking and fat-like descriptive flavor. These results indicate that development of pyrazine compounds are related to improved flavor in beef. Heptanal (C174) was the third variable to enter the equation and it accounted for 4% of the variation in beef identity. Heptanal among other volatile compounds were found to be associated with roasted, sweet, fruity and fatty odor notes of cooked beef (Specht and Baltes, 1994). The next two variables accounted for 3% each of the variation in beef identity. Ethyl ester ethanimidic acid (C434) and benzeneacetaldehyde (C25) entered the equation in their respective order. Benzeneacetaldehyde is described as a sweet, honey aroma (Gasser and Grosch, 1988). Benzeneacetaldehyde also entered the equation for consumer liking.

In Table 15, 2,5-dimethyl-pyrazine (C92) entered the equation first for brown/roasted and accounted for 13% of the variation. Pyrazines are a product of the Maillard reaction and are known for a distinctly roasted aroma. Figure 5 showed that brown/roasted and consumer overall liking were related. Interestingly, both ethyl ester ethanimidic acid (C434) and benzeneacetaldehyde (C25) were variables in the equation for brown roasted, and were also in the equation for beef identity. The similarity was understandable as beef identity and brown/roasted were closely clustered in Figure 5. 2-ethyl-3,5-dimethyl-pyrazine, also in the equation for beef identity, entered the equation third for brown roasted. Two of the first three variables entered into the brown roasted equation were pyrazines and they accounted for 18% of the variation for brown/roasted.

Thirty volatile compounds accounted for 51% of the variation in bloody/ serumy (Table 16). The first variable to enter the equation was 2-pentyl-4,5-dimethyloxazole (C55) and it accounted for 5% of the variation in bloody/serumy. Nonadecane (C69) entered the equation next and accounted for 4% of the variation in bloody/serumy. Carbon disulfide (C31) was the third to enter the equation and accounted for 5% of the variation in bloody/serumy. Sulfur containing compounds have low thresholds and have been shown to greatly contribute to meaty aromas (MacLeod, 1986). The reactions to produce sulfuric compounds were produced by amino acid side chains. Upon heating, these compounds can react with sugars and the Maillard reaction to form volatile sulfur containing compounds (Shahidi, 1994).

Benzaldehyde (C18) accounted for 5% in the variation for the fat-like stepwise regression equation (Table 17). Benzaldehyde is a ring structure that is lipid-derived and is known to have almond oil, or burning aromatic taste (Calkins and Hodgen, 2007). The ß value was negative, indicating that as benzaldehyde increased, fat-like flavor decreased. Considering benzaldehyde was a product of lipid denaturation, these results indicated that fat-like flavor was rated higher in steaks and roasts with less benzaldehyde. The next to enter the equation for fat-like was benzeneacetaldehyde (C25) which accounted for 4% of the variation in fat-like. It also entered the equation for overall like which suggested there is a relationship between benzeneacetaldehyde and consumer like. In Figure 6, benzeneacetaldehyde clustered with burnt, umami, brown/roasted, and beef identity. Other notable compounds to enter the regression equation were 2, 3, 5-trimethyl pyrazine (C128), 2-ethyl-6-methyl-pyrazine (C97), 3-ethyl-2, 5-dimethyl-pyrazine (C77), and methyl-pyrazine (C9).

Thirty-nine volatile chemical compounds were used in the final stepwise regression to account for 58% percent of the variability in metallic (Table 18). Many compounds used to predict metallic flavor were lipid oxidation or heat denaturation products. 2-pentyl-4,5-dimethyloxazole (C55) came into the equation first and accounted for 6% of the variation in metallic which was a product of lipid oxidation. 1-

heptanol entered the equation fourth but only accounted for 3% of the variation in metallic. 1-heptanol is an alcohol with a green, woody aroma and clustered closely with metallic in Figure 6. The remaining compounds in the regression accounted for very small percentages for metallic.

Notable compounds to enter the stepwise regression equation and contribute to liver like flavor (Table 19) were hexadecanal (C376), heptenal (C123), 2-octenal, (C64), and 2-nonenal (C54). All were products of lipid oxidation and have been known to contribute to liver-like flavor (Calkins and Hodgen, 2007). 2- nonenal is known for a cardboardy or fat-like aroma (Shahidi, 1994). While predominantly lipid-derived volatiles entered the step-wise regression, the Calkins and Hodgen (2007) research was not able to attribute liver-like flavor solely to lipid oxidation. This could explain the observance of several pyrazine compounds which are normally more related to beefy and brown/roasted and products of the Maillard reaction. They accounted for 10% of the variation in liver-like. In Figure 6, liver-like was not clustered with any compounds.

The stepwise regression equation for umami was presented in Table 20 and was the most highly predictive flavor attribute. Fifty-six variables were included in the final equation and accounted for 82% of the variation in umami. This was also true in similar research that found twenty-nine variables in the final equation accounted for 60 percent of the variation in umami (Glascock, 2014). Table 20 showed that the first variable to enter the equation for umami was 2(5H)-furanone (C309) which is a ketone that has a roasted aroma. It accounted for 5% of the variation in umami. Shahidi (1994) explained that previous research showed compounds contributing to umami flavor decreased as internal temperature increased. Furthermore, glutamate (contributor to umami flavor) was low when meat was cooked in water. Cooking treatments in this study could account for some of the variation observed. Benzeneacetaldehyde (C25) also entered the equation and accounted for 3% of the variation in umami. It was not surprising that 2(5H)-furanone (C309) and benzeneacetaldehyde (C25) entered into the regression equation as they clustered with umami in Figure 6.

To more closely understand relationships between consumer and trained descriptive sensory attributes, partial least square regression biplot was conducted (Figure 6). As some volatile aromatic compounds were not related to attributes as they were clustered at the center of the bi-plot, these volatile aromatic compounds were excluded from the analyses and the resultant bi-plot is presented in Figure 6 (n=234 volatile aromatic compounds). Volatile aromatic compounds did not cluster with liver-like; however, C38 1-octen-3-ol, C133 hentriacontane and C141 propyl-benzene were clustered with green hay-like. Musty/moldy and cardboardy clustered with C55 2-pentyl-4,5-dimethyloxazole, C61 1-(acetyloxy)-2-propanone, C7 3-hydroxy-2-butanone, and C162 trans-1,2-cyclopentanediol. Metallic was closely clustered with C337 trans-2-tridecenal, C15 1-heptanol and C28 nonenal. Burnt and umami were closely associated with C25 benzeneacetaldehyde and C154 2-furancarboxaldehyde. Bitter was closely associated with C163 1-[2-(2-methylbutyl)phenyl]ethanone, C296 cycloheptane, C121 1,3,5,7-cyclooctatetraene, C124 S,S-dimethyl-N-(4-nitrophenyl)-sulfilimine, , C212 nonacosane, C4 hexanal, C58 thiourea, and C188 methyl ester nonahexacontanoic acid. Sour aromatic was clustered with C158 methyl 4-amino-3-(1',2',3',4'-tetrahydro-2',4'-

dioxopyrimidin-1'-yl)thiophen, C52 dimethyl trisulfide, , C217 2,5-octanedione, C372 docosane, C159 acetone, and C217 2,5-octanedione. Glascock (2014) found a relationship between overall liking and pyrazine compounds. Pyrazine compounds are developed with high heat cooking via the Maillard reaction. While it was surprising that pyrazine compounds were not closely clustered with beef identity or overall liking, four pyrazine compounds were somewhat closely related to burnt, umami, brown/roasted, beef identity and grilled flavor liking. These compounds were 2,5-dimethyl-pyrazine (C92), 2,3-dimethyl-pyrazine (C94), trimethyl-pyrazine (C17), and 2-ethyl-6-methyl-pyrazine (C97).

The aromatic chemical attributes in these regression equations can be used to predict beef flavor attributes. Even though it is not practical to measure all attributes for every steak or roast cooked, examination of conditions that affect or increase aromatic compounds related to beef identity, browned/roasted, bloody/serumy, fat-like, metallic, and umami would influence final beef flavor.

Consumer One-on-One Interviews

In one-on-one interviews, consumers indicated that flavor was extremely important to them when eating beef. They also did not segment tenderness, juiciness and flavor as separate attributes. Neely et al. (1998) found that consumer's perception of taste had not changed over the past two decades. Consumers, in general, indicated that they liked grilled flavor in their beef. They also indicated that the sample that was very bland (Choice and Select bottom round roasts cooked in the crock pot) was liked least. They liked beef because it was versatile, healthy and easy to prepare. Portland, Oregon residents were typically more concerned with how the beef was raised (natural, organic, grass-fed) than consumers from Olathe, Kansas. Consumers from Kansas were more knowledgeable of quality grades in comparison to Portland, and Philadelphia consumers. Light beef eaters like the flavor of beef, but the most common factor identified as to why they do not eat beef more often was the price of beef. They like the recipe flexibility of beef and the nutritional value, mainly protein content, of beef.

CHAPTER V

CONCLUSIONS

Light-beef eaters like beef. Consumers tended to like treatments that used a high temperature grill and steaks that were cooked to lower degrees of doneness. Consumers did not like Choice and Select bottom round roasts cooked in a crockpot, especially when cooked to higher degrees of doneness. They also indicated that they did not like beef that was dry, tough and did not have grilled flavors. Consumers, in general, did not segment juiciness, tenderness and flavor when discussing what beef sample that they liked or did not like, but when eating samples, they scored flavor separate from juiciness and tenderness. Consumers tended to rate juiciness and tenderness similarly or if a sample was dry, they also tended to rate the sample tougher. Consumers and trained sensory panelists rated juiciness and tenderness attributes similarly. Volatile aromatic compounds that were components of an aroma event can be used to predict individual trained sensory beef flavor attributes, but multiple compounds are associated with each flavor attribute. Pyrazine compounds continue to be identified as the class of compounds related to trained descriptive attributes of beef identity, brown/roasted, umami, burnt, and consumer hedonic attributes of grilled flavor liking and overall liking.

Different flavors identified in the beef lexicon and different aromatic volatiles that are characteristic of various beef lexicon attributes, and can be manipulated by muscle, quality grade, pH level, cooking method and final internal temperature endpoint. Results from this study using light beef-eaters were similar to results from Glascock (2104) using moderate to heavy beef-eaters. Differences in flavor were identified in the 20 treatments by trained sensory panelists and by consumers that were light beef-eaters.

These results provided highly predictive regression equations that identified the compounds responsible for major positive beef sensory flavor attributes. Not one single compound was highly predictive of a single beef flavor attribute. It would have been ideal to find one or two chemical compounds that were responsible the major beef sensory flavor descriptive attributes, but as described previously, beef flavor is very complex and has many attributes and compounds involved. This research identified groups of volatile flavor compounds that may help to narrow down what compounds can be used to drive flavor differences.

Ultimately, this research could be used to improve the overall flavor of beef presented to consumers for products not acceptable in flavor. For example, roasts cooked in crock-pots and high pH steaks produced unacceptable eating experiences. One way to improve the roasts would be to sear the outside prior crockpot cooking, this would produce more favorable products that contribute to more overall acceptance like Maillard reaction products. So far, data from this research showed that high heat or extended cookery increases the production of Maillard reaction products, thus increasing overall liking. This research has extended the progress in answering the challenge to improve understanding of beef flavor from Glascock (2014).

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APPENDIX A

TABLES AND FIGURES

Table 1.Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where [1]1= none; 16= extremely intense from Adhikari et al. (2011).

Sensory attributes	Definition	Reference standard flavor scale value unless otherwise defined
Animal hair	The aromatics perceived when raw wool is saturate with water.	Caproic acid (hexanoic acid) = 12.0
Asparagus	A vegetative aroma note associated with canned asparagus.	Asparagus microwaved in water = 6.5
Barnyard	The aromatic characteristic of barn or barnyard; combination of manure, urine, moldy hay, feed, livestock odors.	White pepper in water = 4.5 Tinture of civet = 6.0
Beef identity	Amount of beef flavor identity in the sample.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Beet	The aromatics associated with cooked beets, caramelized, sweet, and earthy.	Canned beet juice in water = 4.0
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody/serumy	The aromatics associated with blood on cooked meat products, closely related to metallic aromatic.	USDA choice strip steak = 5.5 Beef brisket = 6.0
Brown/roasted	A round, full aromatic generally associated with beef suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat Puffs = 5.0
Buttery	The clean, fatty, mild flavor of fresh butter	Land O' Lakes unsalted butter = 7.0

Table 1 (con't).Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where [1]1= none; 16= extremely intense from Adhikari et al. (2011).

Sensory attributes	Definition	Reference standard flavor scale value unless otherwise defined
Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging and petroleum based product such as charcoal liter fluid.	Zip-Loc sandwich bag = 13.0 Clorox in water = 6.5
Cocoa	The aromatics associated with cocoa beans and powdered cocoa. And chocolate bars. Brown, sweet, dusty, often bitter aromatics.	Hershey's cocoa powder in water = 3.0 Hershey's chocolate kiss = 8.5
Cooked milk	A combination of sweet, brown flavor notes and aromatics associated with heated milk.	Babybel original Swiss cheese = 2.5 Dillon's whole milk = 4.5
Cumin	The aromatics associated with cumin and characterized as dry, pungent, woody, and slightly floral.	McCormick ground cumin = 7.0
Dairy	The aromatics associated with products made from cow's milk, such as cream, milk, sour cream or butter milk.	Dillon's reduced fat milk (2%) = 8.0
Fat-like	The aromatics associated with cooked animal fat.	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Floral	The sweet fragrant aromatic associated with flowers.	Welch's white grape juice in water = 5.0
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matters such as parsley, spinach, pea pod, fresh cut grass, etc	Hexanal in propylene glycol (5,000 ppm) = 6.5 (aroma) Fresh parsley water = 9.0
Green-hay	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley and tea leaves	Dry parsley in medium snifter = 5.0 (aroma) Dry parsley in ~30-mL cup = 6.0
Heated-oil	The aromatic associated with fresh oil that is heated.	Wesson vegetable oil cooked 3 min.= 7.0
Leather	Musty, old leather (like old book bindings)	2,3,4-Trimethoxybenzaldehyde = 3.0 (aroma)

Table 1 (con't).Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where [1]1= none; 16= extremely intense from Adhikari et al. (2011).

Sensory attributes	Definition	Reference standard flavor scale value unless otherwise defined
Liver-like	The aromatics associated with cooked organ meat/liver	Beef liver = 7.5 Braunschweiger liver sausage = 10.0 (must taste and swallow)
Metallic	The impression of slightly oxidized metal, such as iron, copper , and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Overall sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet	Post-shredded wheat spoon size = 1.5 Hillshire farms Lit'l beef smokies = 3.0 SAFC ethyl maltol 99% = 4.5 (aroma)
Petroleum-like	The aromatic reminiscent of hydrocarbons such as gasoline or kerosene.	Vaseline petroleum jelly = 3.0 (aroma)
Rancid	The aromatics commonly associated with oxidized fat and oils. These aromatics may include cardboardy, painty, varnish and fishy.	Microwaved Wesson vegetable oil (3 min at high) = 7.0 Microwaved Wesson vegetable oil (5 min at high) = 9.0
Refrigerator-stale	The off flavor associated with a product that has absorbed odors from the refrigerator.	Ground beef cooked and set to cool = 4.5
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Smoky – charcoal	An aromatic associated with meat juices and fat drippings on hot coals which can be acrid, sour, burned, etc.	Wright's Natural Hickory seasoning in water = 9.0 (aroma)
Smoky – wood	Dry, dusty aromatic reminiscent of burning wood.	Wright's Natural Hickory seasoning in water = 7.5 (aroma)
Soapy	The aromatic commonly found in unscented hand soap.	Ivory Bar Soap in water = 6.5 (aroma)

Table 1 (con't).Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where [1]1= none; 16= extremely intense from Adhikari et al. (2011).

Sensory attributes	Definition	Reference standard flavor scale value unless otherwise defined
Sour aromatics	The aromatics associated with sour substances.	Dillon's buttermilk = 5.0
Sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing cow light Swiss cheese = 7.0 Dillon's buttermilk = 9.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Spoiled	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol 10,000 ppm) = 12.0 (aroma)
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% accent flavor enhancer solution = 7.5
Warmed-over	Perception of a product that has been previously cooked and reheated.	80% lean ground beef (reheated) = 6.0

Table 2. Beef flavor attributes[j] least squares means for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Treatment	Beef identity	Brown/ roasted	Bloody/ serumy	Fat-like	Metallic	Liver-like	Umami	Basic Taste: Sweet	Basic Taste: Sour	Basic Taste: Salty	Basic Taste: Bitter
P-value[l]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	0.002	<0.0001	<0.0001	0.001
Choice tenderloin steaks											
Grill, 58°C	6.4^{f}	2.0^{f}	1.7^{cde}	1.5^{fghi}	2.0^{defgh}	0.2^{abcd}	1.0^{cde}	0.2^{cde}	1.9^{efgh}	1.5^{g}	1.5^{e}
Grill, 80°C	6.9^{gh}	2.2^{f}	1.1^{bc}	1.6^{ghi}	1.7^{bcd}	0.1^{ab}	1.1^{e}	0.3^{e}	1.7^{cdef}	1.5^{fg}	1.3^{abcde}
GF[m], 58°C	5.5^{bcd}	0.9^{abc}	2.0^{ef}	1.3^{efg}	2.0^{fgh}	0.4^{bcdef}	0.7^{ab}	0.2^{cde}	2.0^{ghi}	1.3^{cdefg}	1.1^{ab}
GF[m], 80°C	5.7^{de}	1.0^{bc}	0.9^{b}	1.4^{fgh}	1.6^{abc}	0.4^{bcdef}	0.8^{abcd}	0.1^{abcd}	1.6^{cdef}	1.4^{defg}	1.2^{abcd}
High pH top loin steaks											
Grill, 58°C	5.8^{de}	1.5^{e}	2.4^{fg}	1.6^{ghi}	1.8^{bcdef}	0.6^{f}	0.7^{abc}	0.3^{de}	1.4^{bc}	1.3^{bcde}	1.1^{abc}
Grill, 80°C	6.3^{f}	2.3^{fg}	1.2^{bc}	1.7^{hi}	1.4^{ab}	0.4^{bcdef}	0.6^{abcd}	0.2^{abcde}	1.0^{a}	1.3^{cdefg}	1.5^{e}
GF[m], 58°C	4.9^{a}	0.7^{ab}	2.8^{g}	1.6^{ghi}	2.0^{efgh}	0.6^{f}	0.7^{a}	0.2^{cde}	1.0^{ab}	1.2^{bcd}	1.2^{abcd}
GF[m], 80°C	5.3^{abc}	0.8^{abc}	1.3^{bcd}	1.2^{def}	1.5^{ab}	0.4^{bcdef}	0.7^{abc}	0.1^{abcd}	1.1^{ab}	1.2^{abc}	1.1^{a}
Choice bottom round roasts											
Crock pot, 58°C	5.2^{abc}	0.6^{a}	1.2^{bc}	0.9^{abcd}	1.7^{bcde}	0.5^{ef}	0.9^{bcde}	0.1^{abcd}	1.8^{efgh}	1.3^{cdefg}	1.3^{abcde}
Crock pot, 80°C	5.0^{a}	0.6^{a}	0.3^{a}	0.7^{abc}	1.4^{a}	0.5^{ef}	0.6^{a}	0.1^{ab}	1.5^{cde}	1.3^{bcdef}	1.4^{cde}
Select bottom round roasts											
Crock pot, 58°C	5.0^{a}	0.5^{a}	1.3^{bcd}	0.7^{ab}	1.9^{cdefg}	0.6^{f}	0.6^{a}	0.0^{a}	1.9^{fgh}	1.0^{a}	1.3^{bcde}
Crock pot, 80°C	5.0^{ab}	0.6^{a}	0.3^{a}	0.6^{a}	1.5^{ab}	0.5^{cdef}	0.7^{abc}	0.1^{ab}	1.5^{cde}	1.1^{ab}	1.4^{cde}

Table 2 (con't). Beef flavor attributes[j] least squares means for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

								Basic Taste			
Treatment	Beef identity	Brown/ roasted	Bloody/ serumy	Fat-like	Metallic	Liver-like	Umami	Sweet	Sour	Salty	Bitter
Choice top loin steak											
Grill, 58°C	6.5^{fg}	1.9^{f}	2.1^{ef}	1.7^{i}	1.9^{cdefg}	0.2^{abc}	1.0^{de}	0.2^{cde}	1.8^{defg}	1.5^{g}	1.1^{a}
Grill, 80°C	7.2^{h}	2.6^{g}	1.1^{bc}	1.5^{fghi}	1.7^{bcd}	0.0^{a}	1.2^{e}	0.3^{de}	1.5^{cd}	1.5^{efg}	1.4^{cde}
GF[m], 58°C	5.3^{abc}	0.7^{abc}	2.5^{fg}	1.5^{fghi}	2.1^{gh}	0.3^{abcde}	0.7^{abc}	0.2^{bcde}	2.1^{ghi}	1.4^{defg}	1.1^{abc}
GF[m], 80°C	5.5^{cd}	1.1^{cd}	0.9^{ab}	1.2^{def}	1.5^{ab}	0.3^{abcde}	0.8^{abcd}	0.2^{abcde}	1.7^{cdef}	1.3^{bcdef}	1.1^{abc}
Select top sirloin steaks											
Grill, 58°C	5.8^{de}	1.4^{de}	2.5^{fg}	1.0^{cde}	2.2^{h}	0.3^{abcde}	0.5^{a}	0.1^{ab}	2.3^{i}	1.1^{abc}	1.5^{de}
Grill, 80°C	6.1^{ef}	2.0^{f}	1.0^{b}	0.9^{bcd}	1.7^{abc}	0.2^{ab}	0.7^{abc}	0.1^{abcde}	1.8^{efg}	1.2^{bcd}	1.4^{cde}
GF[m], 58°C	5.2^{ab}	0.6^{ab}	1.8^{de}	0.8^{abc}	1.8^{cdefg}	0.3^{bcdef}	0.6^{a}	0.1^{ab}	2.2^{hi}	1.3^{bcde}	1.4^{de}
GF[m], 80°C	5.1^{ab}	0.7^{abc}	1.1^{b}	0.8^{abc}	1.7^{abc}	0.5^{def}	0.6^{a}	0.1^{abc}	1.9^{fgh}	1.1^{ab}	1.4^{cde}
RMSE[e]	0.47	0.40	0.59	0.36	0.32	0.30	0.29	0.15	0.35	0.22	0.27

Table 2 (con't). Beef flavor attributes[j] least squares means for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Treatment	Sour Aromatic	Burnt	Musty/ Moldy	Overall Sweet	Card-Boardy	Green hay-like
P-value[l]	0.007	<0.0001	<0.0001	<0.0001	<0.0001	0.0008
Choice tenderloin steaks						
Grill, 58°C	0.1[abcdef]	0.3[bc]	0.0[abc]	0.7[fg]	0.1[ab]	0.1[def]
Grill, 80°C	0.0[a]	0.4[cd]	0.0[a]	0.7[fg]	0.0[a]	0.0[abc]
GF[m], 58°C	0.2[f]	0.0[a]	0.1[abcd]	0.5[bcdef]	0.0[a]	0.0[bcd]
GF[m], 80°C	0.1[bcdef]	0.1[ab]	0.1[bcde]	0.5[bcdef]	0.3[bcdef]	0.0[abcd]
High pH top loin steaks						
Grill, 58°C	0.0[abcd]	0.1[ab]	0.1[abcde]	0.6[efg]	0.1[ab]	0.0[a]
Grill, 80°C	0.1[bcdef]	0.7[e]	0.0[abc]	0.7[efg]	0.2[bcde]	0.0[abcd]
GF[m], 58°C	0.0[abcdef]	0.0[a]	0.0[abcd]	0.5[bcdef]	0.1[ab]	0.0[ab]
GF[m], 80°C	0.0[abcdef]	0.0[a]	0.0[ab]	0.5[bcdef]	0.5[fg]	0.0[bcd]
Choice bottom round roasts						
Crock pot, 58°C	0.2[def]	0.1[ab]	0.1[cde]	0.2[abcde]	0.4[defg]	0.0[bcde]
Crock pot, 80°C	0.1[cdef]	0.0[a]	0.2[ef]	0.4[defg]	0.5[g]	0.0[bcd]
Select bottom round roasts						
Crock pot, 58°C	0.1[cdef]	0.0[a]	0.2[ef]	0.8[a]	0.5[g]	0.0[abcd]
Crock pot, 80°C	0.1[cdef]	0.0[a]	0.3[f]	0.7[abcde]	0.4[efg]	0.0[abcd]

Table 2 (con't). Beef flavor attributes[j] least squares means for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Treatment	Sour Aromatic	Burnt	Musty/ Moldy	Overall Sweet	Card- Boardy	Green hay-like
Choice top loin steak						
Grill, 58°C	0.0^{ab}	0.3^{bc}	0.0^{abc}	0.8^{g}	0.2^{abcd}	0.0^{ab}
Grill, 80°C	0.1^{def}	0.6^{de}	0.1^{abcd}	0.7^{fg}	0.0^{a}	0.0^{abcd}
GF[m], 58°C	0.0^{abc}	0.0^{a}	0.0^{abc}	0.5^{cdef}	0.1^{ab}	0.0^{cdef}
GF[m], 80°C	0.2^{f}	0.0^{a}	0.3^{f}	0.5^{bcdef}	0.4^{efg}	0.1^{abcd}
Select top sirloin steaks						
Grill, 58°C	0.0^{ab}	0.1^{bc}	0.1^{bcde}	0.3^{abc}	0.1^{abc}	0.0^{bcde}
Grill, 80°C	0.0^{def}	0.3^{de}	0.1^{abcde}	0.3^{abcd}	0.2^{abcd}	0.1^{abc}
GF[m], 58°C	0.0^{abc}	0.0^{a}	0.2^{def}	0.3^{ab}	0.3^{cdefg}	0.0^{ef}
GF[m], 80°C	0.2^{f}	0.0^{a}	0.2^{bc}	0.4^{abcd}	0.4^{efg}	0.1^{f}
RMSE[e]	0.15	0.26	0.16	0.25	0.23	0.08

Table 2 (con't). Beef flavor attributes[j] least squares means for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Treatment	Juiciness	Muscle Fiber Tenderness	Connective Tissue Amount	Overall Tenderness	Warner- Bratzler Shear Force, kg
P-value[l]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Choice tenderloin steaks					
Grill, 58°C	10.9^{efgh}	13.1^{g}	13.6^{e}	13.1^{i}	1.9^{ab}
Grill, 80°C	10.7^{efg}	13.3^{g}	13.7^{e}	13.2^{i}	2.8^{cde}
GF[m], 58°C	11.1^{fghi}	13.4^{g}	13.5^{e}	13.4^{i}	1.8^{a}
GF[m], 80°C	10.4^{def}	12.6^{fg}	13.5^{e}	12.4^{hi}	2.8^{cdef}
High pH top loin steaks					
Grill, 58°C	12.1^{i}	11.8^{def}	11.8^{bcd}	11.7^{fgh}	2.5^{bc}
Grill, 80°C	10.4^{def}	10.8^{bcd}	11.6^{bc}	10.8^{def}	3.5^{fg}
GF[m], 58°C	12.0^{i}	11.9^{ef}	12.1^{bcd}	11.9^{gh}	2.5^{bc}
GF[m], 80°C	10.6^{efg}	11.2^{cde}	12.1^{bcd}	11.1^{defg}	3.3^{defg}
Choice bottom round roasts					
Crock pot, 58°C	9.6^{bcd}	9.6^{ab}	9.8^{a}	9.3^{abc}	3.3^{defg}
Crock pot, 80°C	8.2^{b}	9.0^{a}	9.8^{a}	8.8^{a}	3.9^{gh}
Select bottom round roasts					
Crock pot, 58°C	8.7^{b}	9.2^{a}	10.2^{a}	9.1^{a}	3.4^{efg}
Crock pot, 80°C	7.7^{a}	8.9^{a}	10.3^{a}	8.8^{a}	4.2^{h}

Table 2 (con't). Beef flavor attributes[j] least squares means for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Treatment	Juiciness	Muscle Fiber Tenderness	Connective Tissue Amount	Overall Tenderness	Warner- Bratzler Shear Force, kg
Choice top loin steaks					
Grill, 58°C	12.0[i]	11.6[def]	12.1[bcd]	11.5[efgh]	2.4[bc]
Grill, 80°C	10.3[def]	10.8[cd]	12.6[d]	10.8[defg]	2.9[cdef]
GF[m], 58°C	11.8[hi]	11.4[cde]	12.0[bcd]	11.3[defgh]	2.5[bc]
GF[m], 80°C	10.1[cde]	11.0[cde]	12.3[cd]	11.0[defg]	3.0[cdef]
Select top sirloin steaks					
Grill, 58°C	11.4[ghi]	10.4[bc]	11.8[bc]	10.3[bcd]	2.9[cdef]
Grill, 80°C	9.8[bc]	9.3[a]	11.9[bcd]	9.2[ab]	4.3[h]
GF[m], 58°C	10.3[def]	10.5[bc]	12.2[bcd]	10.5[cde]	2.6[bcd]
GF[m] , 80°C	9.2[bc]	9.1[a]	11.4[b]	9.1[a]	4.2[b]
RMSE[k]	0.99	1.15	0.85	1.21	0.73

[abcdef]Mean values within a column and effect followed by the same letter are not significantly different ($P \geq 0.05$).

[j] Aroma measured where 0 = none and 15 = extremely intense

[k] Root Mean Square Error

[l] P-value from analysis of variance tables.

[m] George Foreman

Table 3. Demographic frequencies for light beef consumers (n=239) across three cities.

Question	Number of Respondents	Percentage of Respondents
Sex		
Male	71	29.7
Female	168	70.3
Age		
20 years or younger	4	1.7
21 - 25 years	51	21.3
26 - 35 years	67	28.0
36 - 45 years	40	16.7
46 - 55 years	53	22.2
56 - 65 years	13	5.4
66 years and older	11	4.6
Household income		
Below $25,000	47	19.8
$25,001 - $49,999	61	25.6
$50,000 - $74,999	50	21.0
$75,000 - $99,999	38	16.0
$100,000 or more	42	17.7
Household size including yourself		
1	36	15.1
2	80	33.5
3	57	23.9
4	42	17.6
5	16	6.7
6 or more	8	3.4
Employment level		
Not employed	35	14.6
Part-time	59	24.7
Full-time	145	60.7

Proteins consumed at home or at a restaurant (away from home)

At Home	**Do not Consume**	**Consume**	**Do not Consume**	**Consume**
Chicken	6	233	2.5	97.5
Beef	6	233	2.5	97.5
Pork	31	208	13.0	87.0
Fish	57	182	23.9	76.1
Lamb	192	47	80.3	19.7
Eggs	9	230	62.8	37.2
Soy Based Products	150	89	62.8	37.2

Table 3 (con't). Demographic frequencies for light beef consumers (n=239) across three cities.

Question	Number of Respondents		Percentage of Respondents	
Away from Home/Restaurant	**Do not Consume**	**Consume**	**Do not Consume**	**Consume**
Chicken	12	227	5.0	95.0
Beef	6	233	2.5	97.5
Pork	41	198	17.2	82.9
Fish	38	201	15.9	84.1
Lamb	149	90	62.3	37.7
Eggs	24	215	10.0	90.0
Soy Based Products	155	84	64.9	35.2
Weekly consumption of protein				
Beef				
0	1		0.4	
1	104		43.5	
2	67		28.0	
3	50		20.9	
4	14		5.9	
5	3		1.3	
Pork				
0	29		12.2	
1	125		52.7	
2	69		29.1	
3	12		5.1	
4	2		0.8	
Lamb				
0	127		54.7	
1	95		41.0	
2	8		3.5	
3	2		0.9	
Chicken				
0	4		1.7	
1	62		26.1	
2	97		40.8	
3	58		24.4	
4	17		7.1	
Fish				
0	30		12.6	
1	134		56.3	
2	65		27.3	
3	7		2.9	
4	2		0.8	
Soy Based Products				
0	86		37.4	
1	102		44.4	
2	28		12.2	
3	11		4.8	
4	3		1.3	

Table 3 (con't). Demographic frequencies for light beef consumers (n=239) across three cities.

Question	Number of Respondents		Percentage of Respondents	
What cooking method do you prefer to use when cooking a beef steak?				
	Do not use	**Use**	**Do not use**	**Use**
Pan-frying or using a skillet on the stove	124	115	51.9	48.1
Stir Fry	136	103	56.9	43.1
Grilling Outside	46	193	19.3	80.7
Oven Broiling	165	74	69.0	31.0
Oven Baking	171	68	71.6	28.5
Microwave	232	7	97.1	2.9
Electric Appliance (George Foreman Grill or other electric grill)	191	48	79.9	20.1
Degree of doneness preference				
Rare	6		2.5	
Medium Rare	93		38.9	
Medium	70		29.3	
Medium Well	57		23.9	
Well	12		5.0	
Very Well	1		0.4	
When purchasing beef, what do you typically tend to buy at the retail store?				
Do not purchase at retail store	2		0.8	
Grass Fed	49		20.5	
Dry Aged	7		2.9	
Organic	22		9.21	
Traditional beef at the retail store	159		66.5	
What flavor or types of cuisines do you like?				
	Do not Eat	**Eat**	**Do not eat**	**Eat**
American	11	228	4.6	95.4
Barbeque	16	223	6.7	93.3
Mexican/Spanish	15	224	6.3	93.7
Indian	118	121	49.4	50.6
Chinese	25	214	10.5	89.5
Greek	100	139	41.8	58.2
Japanese	89	150	37.2	62.8
Italian	27	212	11.3	88.7
French	113	126	47.3	52.7
Thai	80	159	33.5	66.5
Lebanese	171	68	71.6	28.5

Table 4. Least squares means for consumer attributes for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Treatment	Overall liking	Overall flavor liking	Beef flavor liking	Grill flavor liking	Juiciness liking	Tenderness liking
P-value[m]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Choice tenderloin steaks						
Grill, 58°C	7.1^{l}	6.9^{i}	6.8^{ij}	6.5^{gh}	7.0^{jk}	7.9^{k}
Grill, 80°C	7.0^{l}	7.0^{i}	7.0^{ij}	7.0^{hi}	6.5^{ghi}	7.3^{ij}
George Foreman, 58°C	6.7^{jkl}	6.6^{hi}	6.5^{hi}	5.7^{f}	7.2^{k}	7.7^{jk}
George Foreman, 80°C	6.2^{hij}	6.0^{efg}	6.1^{fgh}	5.5^{ef}	6.1^{efg}	7.2^{i}
High pH top loin steaks						
Grill, 58°C	6.3^{efgh}	5.8^{defg}	5.9^{defg}	5.6^{f}	6.8^{ijk}	6.4^{fg}
Grill, 80°C	6.5^{ijk}	6.3^{gh}	6.3^{gh}	6.5^{gh}	6.5^{ghij}	6.5^{gh}
George Foreman, 58°C	5.2^{bcde}	5.2^{bc}	5.3^{abc}	4.7^{bc}	6.1^{efg}	5.9^{ef}
George Foreman, 80°C	5.4^{cdef}	5.3^{bc}	5.6^{cdef}	5.0^{cd}	5.7^{de}	5.5^{de}
Choice bottom round roasts						
Crockpot, 58°C	5.0^{bc}	5.1^{ab}	5.4^{abcd}	4.2^{ab}	6.1^{eg}	5.4^{cd}
Crockpot, 80°C	4.5^{a}	5.0^{ab}	5.2^{abc}	4.5^{ab}	3.7^{ab}	4.0^{a}
Select bottom round roasts						
Crockpot, 58°C	4.8^{ab}	4.9^{ab}	5.1^{ab}	4.1^{a}	5.9^{ef}	5.2^{cd}
Crockpot, 80°C	4.4^{a}	4.7^{a}	5.1^{a}	4.2^{a}	3.3^{a}	3.9^{a}

Table 4 (con't). Least squares means for consumer attributes for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Treatment	Overall liking	Overall flavor liking	Beef flavor liking	Grill flavor liking	Juiciness liking	Tenderness liking
Choice top loin steak						
Grill, 58°C	6.8^{kl}	6.9^{i}	7.0ij	6.8^{ghi}	7.0^{jk}	6.4^{fg}
Grill, 80°C	6.8^{kl}	7.1^{i}	7.1^{j}	7.2^{i}	6.1^{efg}	6.2^{fg}
George Foreman, 58°C	6.1^{ghi}	6.2^{fgh}	6.2^{gh}	5.3^{def}	6.7^{hijk}	6.6^{h}
George Foreman, 80°C	5.7^{efgh}	5.9^{defg}	6.0^{efg}	5.3^{def}	5.3^{d}	5.6^{de}
Select top sirloin steaks						
Grill, 58°C	6.7^{kl}	6.9^{i}	7.0^{ij}	6.5^{gh}	7.1^{k}	6.5^{fgh}
Grill, 80°C	5.6^{defg}	6.2^{fgh}	6.3^{gh}	6.4^{g}	4.5^{c}	4.0^{bc}
George Foreman, 58°C	5.8^{fgh}	5.7^{cdef}	5.9^{efg}	5.0^{cde}	6.3^{fgh}	6.4^{fgh}
George Foreman, 80°C	5.1^{bcd}	5.4^{bcd}	5.6^{bcde}	5.0^{cd}	4.1^{bc}	4.7^{b}
RMSE[n]	2.00	2.00	1.97	1.91	2.04	2.13

[abcdefghijkl]Mean values within a column followed by the same letter are not significantly different ($P \geq 0.05$).
[m]P-value from analysis of variance tables.
[n]Root Mean Square Error

Table 5. Simple correlation coefficients[a] between consumer sensory attributes and trained descriptive sensory panel flavor attributes.

Effect	Overall liking	Overall flavor liking	Beef flavor liking	Grill flavor liking	Juiciness liking	Tenderness liking
Beef identity	0.55	0.56	0.54	0.65	0.28	0.38
Brown/roasted	0.56	0.58	0.57	0.73	0.28	0.34
Bloody/serumy	0.24	0.19	0.14	0.13	0.46	0.32
Fat-like	0.46	0.42	0.38	0.46	0.48	0.52
Metallic	0.21	0.20	0.18	0.10	0.32	0.24
Liver-like	0.19	-0.22	-0.22	-0.28	-0.01	-0.10
Umami	0.31	0.30	0.29	0.34	0.20	0.24
Sweet	0.26	0.30	0.29	0.33	0.20	0.23
Sour	0.11	0.12	0.12	-0.03	0.09	0.07
Salty	0.38	0.35	0.35	0.40	0.22	0.31
Bitter	0.07	0.06	0.09	0.09	0.00	0.03
Overall sweet	0.29	0.33	0.31	0.38	0.26	0.27
Cardboardy	0.34	-0.31	-0.27	-0.33	-0.30	-0.35
Warmed over flavor	-0.16	-0.18	-0.23	-0.24	-0.23	-0.24
Sour dairy	0.26	0.30	0.27	0.31	0.14	0.20
Sour aromatic	-0.15	-0.12	-0.13	-0.15	-0.13	-0.13
Burnt	0.37	0.34	0.35	0.47	0.19	0.19
Musty-earthy/humus	0.34	-0.31	-0.30	-0.33	-0.33	-0.35
Juiciness	0.47	0.41	0.38	0.37	0.59	0.53
Muscle fiber tenderness	0.47	0.38	0.35	0.34	0.49	0.66
Connective tissue amount	0.50	0.43	0.41	0.43	0.39	0.59
Overall tenderness	0.47	0.38	0.45	0.34	0.48	0.65
Warner-Bratzler SF	-0.43	-0.32	-0.29	-0.26	-0.56	-0.63

[a] Simple correlation coefficients ≥ 0.13 are significant ($P \leq 0.05$).

Table 6. Stepwise linear regression for prediction of consumer overall like as the dependent variable and consumer attributes as independent variables.

Step	Variables[a]	Estimate[b]	Partial R^2	Equation[c] R^2
	Intercept	-0.24		
1	Overall flavor liking	0.60	0.80	0.80
2	Tenderness liking	0.11	0.05	0.84
3	Beef flavor liking	0.06	0.003	0.85
4	Juiciness liking	0.07	0.002	0.85
5	Grilled flavor liking	0.19	0.001	0.85

[a]Variables measured using 9-point hedonic and intensity scales were 1=extremely dislike or none; 9=extremely like or extremely intense.

[b]Estimates are the □-values for the final regression equation when the defined variable was included.

[c]Estimates are the □-values for the final regression equation when the defined variable was included.

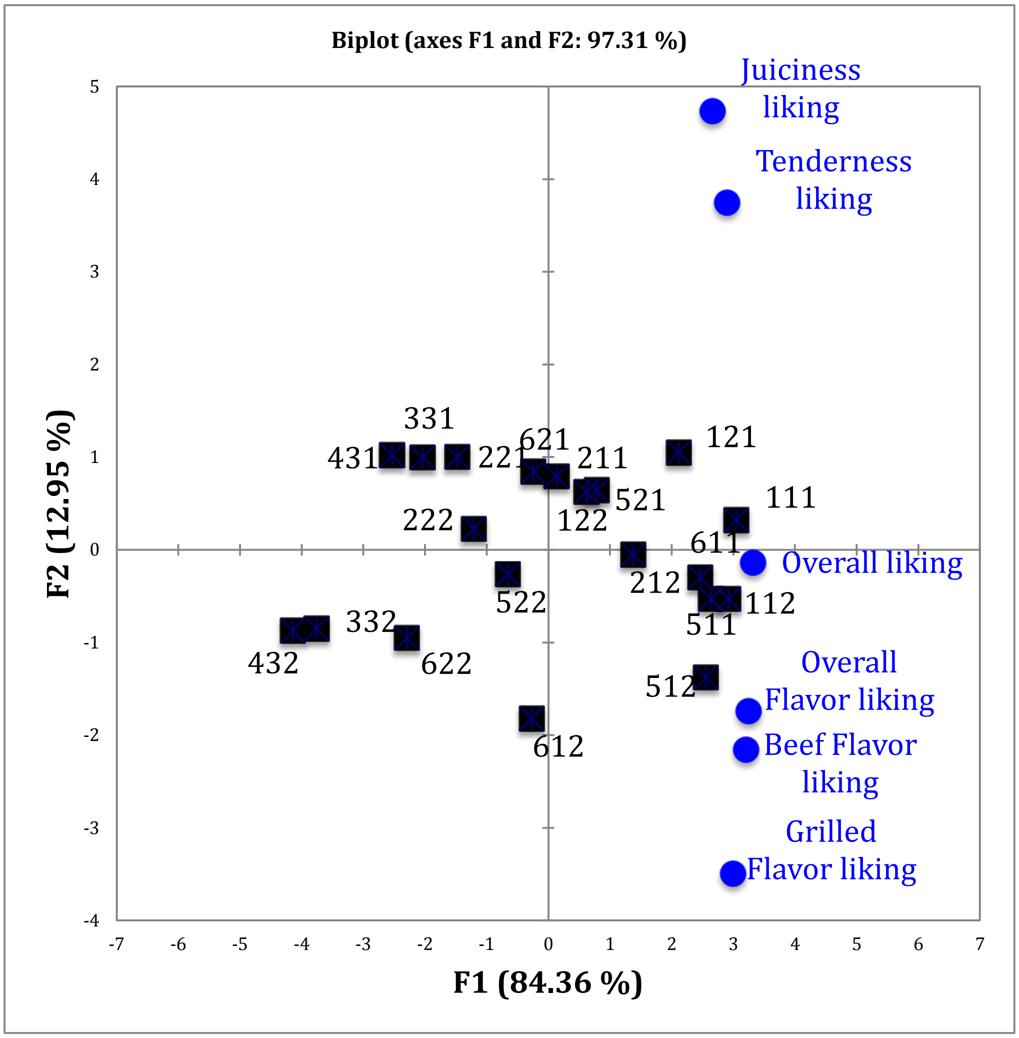

Figure 1. Principal component biplot of consumer liking sensory attributes (in blue) and 20 treatments (in black) where 111 = tenderloin steaks grilled to 58°C; 112 = tenderloin steaks grilled to 80°C; 121 = tenderloin steaks George Foreman to 58°C; 122 = tenderloin steaks George Foreman to 80°C; 211 = high pH top loin steaks grilled to 58°C; 212 = high pH top loin steaks grilled to 80°C; 221 = high pH top loin steaks George Foreman to 58°C; 222 = high pH top loin steaks George Foreman to 80°C; 331 = Choice bottom round roasts cooked in a crockpot to 58°C; 332 = Choice bottom round roasts cooked in a crockpot to 80°C; 431 = Select bottom round roasts cooked in a crockpot to 58°C; 432 = Select bottom round roasts cooked in a crockpot to 80°C; 511 = Choice top loin steaks grilled to 58°C; 512 = Choice top loin steaks grilled to 80°C; 521 = Choice top loin steaks George Foreman to 58°C; 522 = Choice top loin steaks George Foreman to 80°C; and 611 = Select top sirloin steaks grilled to 58°C; 612 = Select top sirloin steaks grilled to 80°C; 621 = Select top sirloin steaks George Foreman to 58°C; 622 = Select top sirloin steaks George Foreman to 80°C.

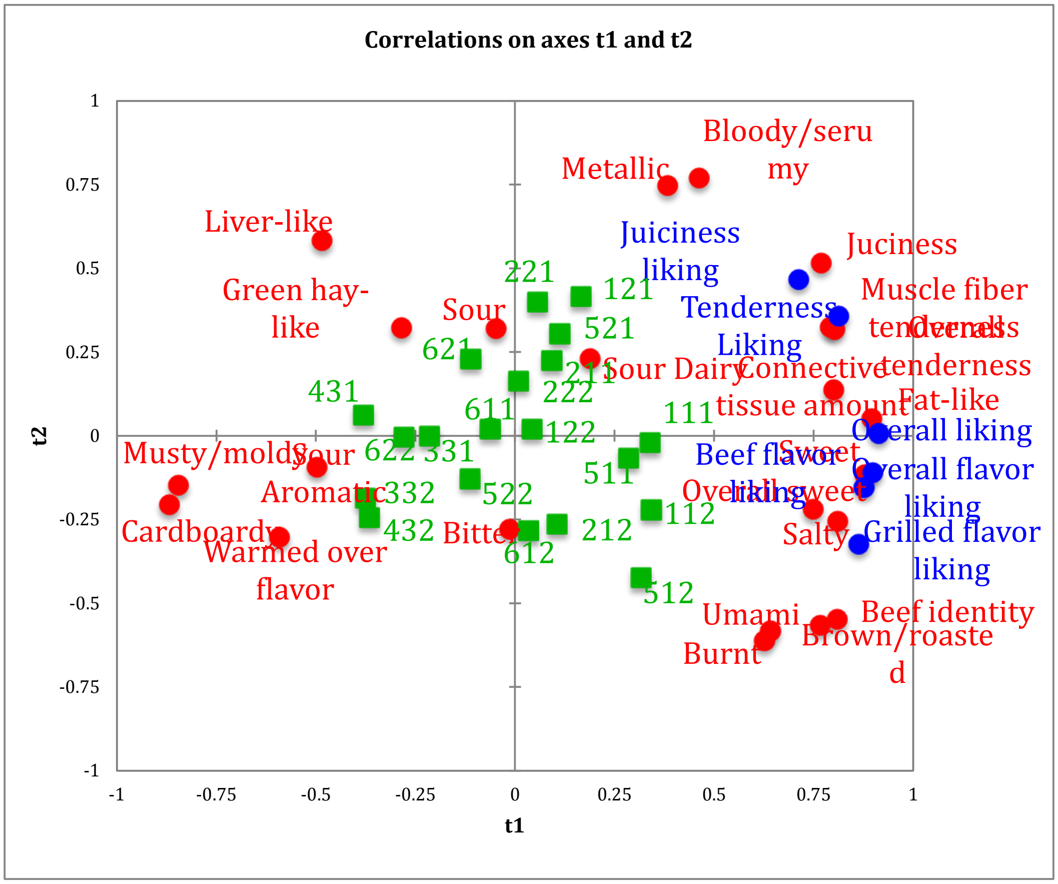

Figure 2. Partial least squares regression biplot (R^2 = **80.2**) of trained descriptive flavor attributes from the Beef Lexicon (in red), consumer sensory attributes (in blue), and 20 treatments (in green) where 111 = tenderloin steaks grilled to 58°C; 112 = tenderloin steaks grilled to 80°C; 121 = tenderloin steaks George Foreman to 58°C; 122 = tenderloin steaks George Foreman to 80°C; 211 = high pH top loin steaks grilled to 58°C; 212 = high pH top loin steaks grilled to 80°C; 221 = high pH top loin steaks George Foreman to 58°C; 222 = high pH top loin steaks George Foreman to 80°C; 331 = Choice bottom round roasts cooked in a crockpot to 58°C; 332 = Choice bottom round roasts cooked in a crockpot to 80°C; 431 = Select bottom round roasts cooked in a crockpot to 58°C; 432 = Select bottom round roasts cooked in a crockpot to 80°C; 511 = Choice top loin steaks grilled to 58°C; 512 = Choice top loin steaks grilled to 80°C; 521 = Choice top loin steaks George Foreman to 58°C; 522 = Choice top loin steaks George Foreman to 80°C; and 611 = Select top sirloin steaks grilled to 58°C; 612 = Select top sirloin steaks grilled to 80°C; 621 = Select top sirloin steaks George Foreman to 58°C; 622 = Select top sirloin steaks George Foreman to 80°C.

Table 7. Least squares means for chemical components for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Effect	pH	Non-Heme iron, mg/g	Myoglobin mg/g	Moisture %	Lipid %
p-value[e]	<0.001	0.20	0.59	<0.001	<0.001
Choice tenderloin steaks	5.43[a]	3.63	3.31	71.15[b]	5.60[c]
High pH top loin steaks	6.56[b]	4.57	2.74	71.02[b]	6.74[c]
Choice bottom round roasts	5.43[a]	3.42	2.87	74.33[cd]	3.22[b]
Select bottom round roasts	5.54[a]	3.25	2.91	75.46[d]	1.47[a]
Choice top loin steaks	5.42[a]	4.96	2.90	67.25[a]	10.13[d]
Select top sirloin steaks	5.54[a]	3.83	2.88	73.17[c]	3.32[b]
RMSE[f]	0.159	1.643	0.698	1.450	1.515

[a,b,c] Mean values within a column and effect followed by the same letter are not significantly different ($P \geq 0.05$).
[f] Root Mean Square Error
[e] P-value from analysis of variance tables.

Table 8. Least squares means for fatty acid components for 20 beef cuts across cooking methods, USDA Quality Grade, pH and internal temperature endpoints treatments.

Effect	14:0	15:0	16:0	16:1	17:1 cis	18:0	18:1	18:2	20:4	20:5	24:0	22:6
p-value[e]	0.10	0.84	0.04	0.004	0.15	0.001	0.35	0.005	0.001	0.56	0.22	0.18
Choice tenderloin steaks	3.23	0.48	24.97[b]	2.55[a]	1.13	14.62[cd]	32.04	5.95[ab]	1.03[ab]	0.01	0.11	0.18
High pH top loin steaks	3.28	0.47	24.03[ab]	3.06[abc]	1.03	14.23[bcd]	33.59	4.94[a]	0.84[a]	0.21	0.14	0.29
Choice bottom round roasts	2.97	0.44	23.27[a]	3.64[c]	0.95	11.91[a]	34.93	6.44[bc]	1.36[bc]	0.04	0.15	0.17
Select bottom round roasts	2.82	0.46	23.00[a]	3.28[bc]	1.08	12.90[ab]	33.58	7.29[c]	1.75[c]	0.07	0.11	0.27
Choice top loin steak	3.75	0.48	23.35[a]	3.33[bc]	0.98	13.35[abc]	31.96	4.92[a]	0.95[ab]	0.14	0.12	0.17
Select top sirloin steaks	2.73	0.47	23.31[a]	2.80[ab]	1.13	15.18[d]	33.51	5.77[ab]	1.35[bc]	0.08	0.04	0.27
RMSE[f]	0.820	0.069	1.471	0.627	0.190	1.602	3.263	1.426	0.455	0.244	0.104	0.248

[a,b,c] Mean values within a column and effect followed by the same letter are not significantly different (P ≥ 0.05).
[f] Root Mean Square Error
[e] P-value from analysis of variance tables.

Table 9. Simple correlation coefficients[a] between chemical measures and trained descriptive sensory panel flavor attributes.

Effect	pH	Non-Heme iron, mg/g	Myoglobin mg/g	Moisture %	Lipid %	14:0	15:0	16:0	16:1
Flavor attributes									
Beef identity	-0.03	0.18	0.04	-0.67	0.65	0.21	0.15	0.35	-0.28
Brown/roasted	0.19	0.27	0.11	-0.64	0.60	0.19	0.12	0.24	-0.34
Bloody/serumy	0.33	0.21	-0.17	-0.55	0.50	0.18	0.06	-0.01	-0.14
Fat-like	0.32	0.23	-0.08	-0.62	0.66	0.22	0.01	0.14	-0.10
Metallic	-0.06	0.16	-0.02	-0.35	0.23	0.15	0.06	-0.07	-0.12
Liver-like	0.31	-0.20	-0.15	0.14	-0.17	0.11	0.04	-0.19	0.22
Umami	-0.07	0.02	0.16	-0.36	0.35	0.14	0.02	0.10	-0.06
Sweet	0.06	0.13	0.19	-0.55	0.60	0.15	0.02	0.20	-0.17
Sour	-0.62	-0.18	0.13	0.09	-0.19	-0.06	0.04	-0.06	-0.18
Salty	-0.04	0.23	0.11	-0.52	0.55	0.26	0.14	0.28	-0.02
Bitter	0.03	0.09	0.11	0.29	-0.34	-0.23	-0.20	-0.29	-0.03
Overall sweet	0.16	0.25	0.07	-0.55	0.61	0.17	-0.12	0.04	-0.04
Cardboardy	-0.12	-0.14	-0.00	0.50	-0.48	-0.13	-0.14	-0.24	0.29
Warmed over flavor	-0.11	0.00	-0.15	0.20	-0.09	0.10	0.09	-0.20	0.27
Sour dairy	-0.22	-0.01	-0.00	-0.27	0.17	-0.06	-0.11	-0.08	-0.34
Sour aromatic	-0.20	0.01	-0.03	0.05	-0.08	-0.03	-0.18	0.04	0.06
Burnt	0.41	0.31	0.06	-0.39	0.41	-0.00	-0.02	-0.05	-0.22
Musty-earthy/humus	-0.27	-0.15	-0.13	0.48	-0.46	-0.20	-0.12	-0.25	0.07
Juiciness	0.30	0.19	-0.07	-0.65	0.67	0.20	0.01	0.10	-0.19
MF tenderness	0.15	0.16	0.10	-0.48	0.48	0.22	0.08	0.27	-0.25
Connective tissue	0.07	0.14	0.12	-0.49	0.47	0.15	0.08	0.28	-0.40
Overall tenderness	0.15	0.17	0.11	-0.48	0.49	0.21	0.08	0.25	-0.27

[a] Simple correlation coefficients ≥0.15 are significant (P≤0.05).

Table 9 (con't). Simple correlation coefficients[a] between chemical measures and trained descriptive sensory panel flavor attributes.

Effect	17:1 Cis	18:0	18:1	18:2	20:4	20:5	24:0	22:6
Flavor attributes								
Beef identity	0.10	0.18	-0.20	-0.26	-0.36	-0.05	-0.05	-0.16
Brown/roasted	0.08	0.29	-0.24	-0.34	-0.43	-0.03	-0.08	-0.11
Bloody/serumy	-0.04	0.38	-0.18	-0.45	-0.25	0.15	-0.04	0.07
Fat-like	-0.12	0.04	-0.18	-0.38	-0.42	0.02	0.08	-0.12
Metallic	0.04	0.33	-0.21	-0.29	0.01	-0.07	-0.17	-0.02
Liver-like	-0.18	-0.16	-0.12	-0.02	0.17	0.15	0.29	0.09
Umami	0.05	-0.14	-0.07	-0.21	-0.26	-0.05	0.03	-0.13
Sweet	0.02	0.09	-0.14	-0.28	-0.33	-0.07	0.02	-0.18
Sour	0.11	0.19	-0.11	0.00	0.14	-0.16	-0.24	-0.03
Salty	-0.03	-0.01	-0.21	-0.14	-0.31	-0.13	0.18	-0.26
Bitter	0.08	-0.09	-0.00	0.18	0.25	-0.06	0.01	-0.01
Overall sweet	-0.23	-0.13	-0.16	-0.33	-0.36	-0.02	0.16	-0.19
Cardboardy	-0.10	-0.26	0.17	0.32	0.27	-0.01	0.07	0.01
Warmed over flavor	-0.11	-0.10	-0.11	0.18	0.13	-0.06	0.06	-0.02
Sour dairy	-0.03	0.10	-0.12	-0.38	-0.29	-0.12	-0.36	-0.04
Sour aromatic	-0.21	-0.18	-0.18	-0.01	-0.05	-0.04	0.10	-0.07
Burnt	-0.05	0.16	-0.11	-0.10	-0.19	0.07	0.05	-0.04
Musty-earthy/humus	0.00	-0.08	0.17	0.28	0.28	0.00	-0.05	0.05
Juiciness	-0.10	0.25	-0.21	-0.43	-0.40	0.07	-0.02	-0.07
MF tenderness	-0.05	0.13	-0.27	-0.20	-0.34	-0.01	0.06	-0.11
Connective tissue	0.12	0.39	-0.23	-0.20	-0.35	-0.00	-0.13	-0.49
Overall tenderness	-0.05	0.15	-0.27	-0.20	-0.35	-0.01	0.03	-0.48

[a] Simple correlation coefficients ≥0.15 are significant (P≤0.05).

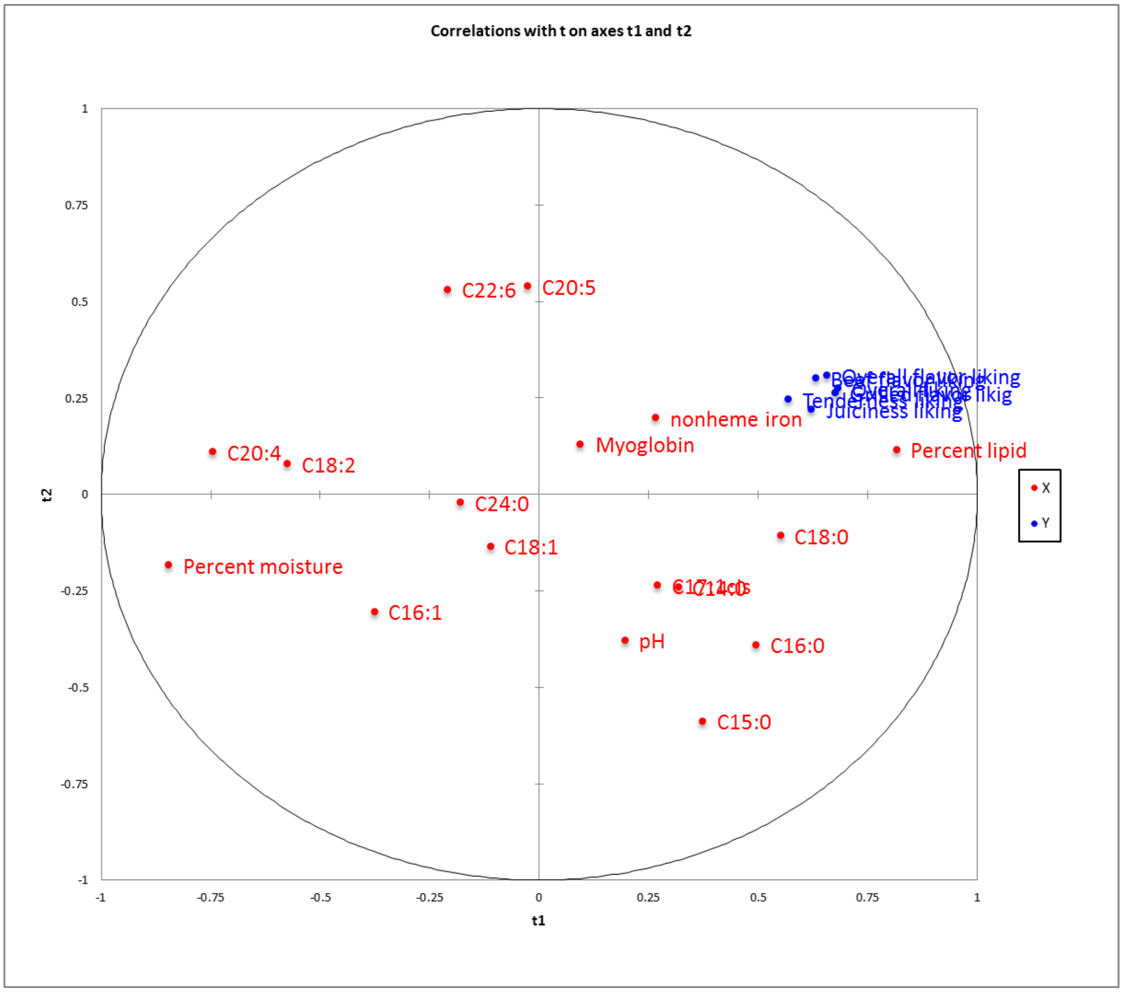

Figure 3. Partial least squares regression biplot of consumer liking sensory attributes (in blue) and chemical data (in red).

Table 10. Simple correlation coefficients[a] between raw chemical data and consumer sensory attributes.

Effect	Overall liking	Overall flavor liking	Beef flavor liking	Grill flavor liking	Juiciness liking	Tenderness liking
pH	0.01	-0.08	-0.09	0.02	0.24	0.09
Non-heme iron mg/g	0.19	0.19	0.20	0.22	0.11	0.09
Myoglobin mg/g	0.09	0.04	0.12	0.06	0.01	0.10
Moisture %	-0.61	-0.59	-0.59	-0.63	-0.59	-0.49
Lipid%	0.58	0.56	0.55	0.57	0.61	0.47
14:0	0.13	0.09	0.08	0.12	0.22	0.16
15:0	0.14	0.09	0.13	0.11	0.08	0.10
16:0	0.34	0.31	0.30	0.23	0.27	0.34
16:1	-0.38	-0.38	-0.36	-0.34	-0.23	-0.33
17:1 cis	0.19	0.18	0.20	0.14	0.00	0.12
18:0	0.34	0.33	0.33	0.38	0.16	0.19
18:1	-0.19	-0.15	-0.15	-0.18	-0.21	-0.21
18:2	-0.32	-0.35	-0.29	-0.39	-0.37	-0.25
20:4	-0.42	-0.39	-0.32	-0.41	-0.47	-0.43
20:5	0.03	0.00	-0.01	0.02	0.19	0.09
24:0	-0.16	-0.18	-0.15	-0.16	-0.00	-0.09
22:6	-0.05	-0.05	-0.06	-0.05	0.05	0.01

[a] Simple correlation coefficients ≥0.15 aren significant (P≤0.05).

Table 11. Stepwise linear regression for prediction of consumer overall like as the dependent variable and chemical data as independent variables.

Step	Variables[a]	Estimate[b]	Partial R^2	Equation[c] R^2
	Intercept	18.92		
1	Moisture %	-0.41	0.37	0.37
2	16:1	-0.17	0.11	0.48

[a]Variables measured using 9-point hedonic and intensity scales were 1=extremely dislike or none; 9=extremely like or extremely intense.
[b]Estimates are the □-values for the final regression equation when the defined variable was included.
[c]Estimates are the □-values for the final regression equation when the defined variable was included.

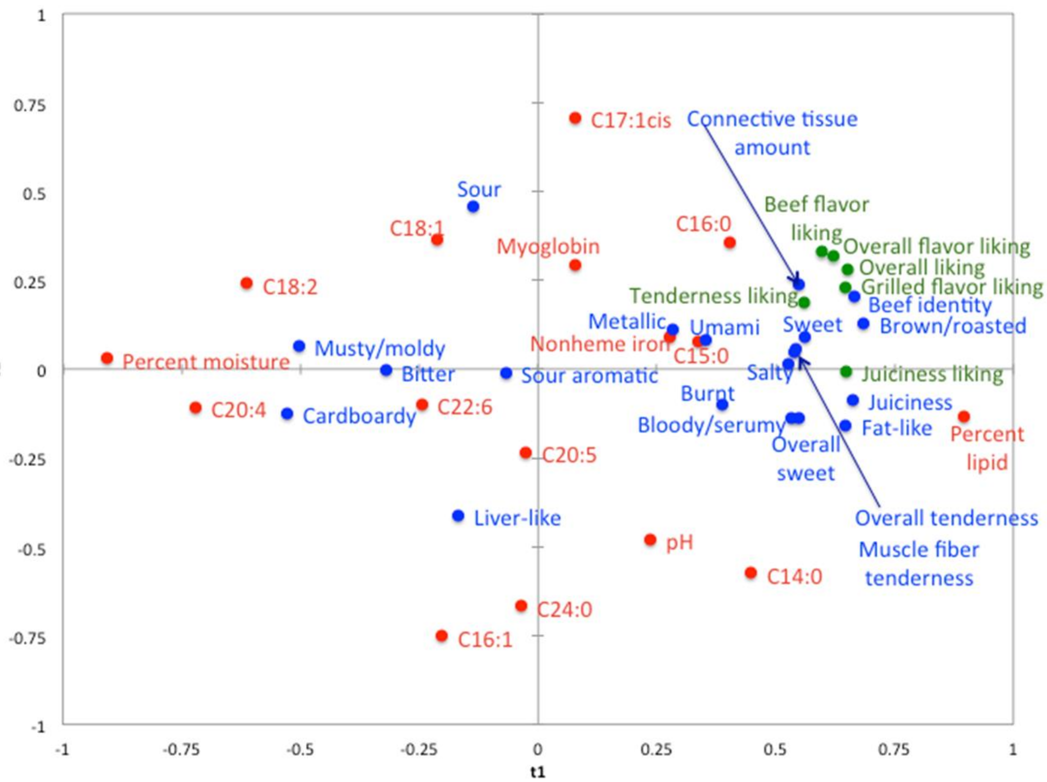

Figure 4. Partial least squares regression biplot ($R^2 = 31.6$) of trained descriptive flavor attributes from the Beef Lexicon (in blue), consumer sensory attributes (in green), and raw meat chemical measures (in red).

Table 12. Overall means (n=186) and standard deviation values for volatile, aromatic chemicals identified by the GC/mass spectrometer.

Code:	Volatile, Aromatic Chemical	Mean	Standard deviation
C1	2,3-Butanedione	85013	175108.9
C2	Butanal, 3-methyl-	85154	252741.7
C3	Butanal, 2-methyl-	64891	242820.3
C4	Hexanal	3012695	3887556.3
C6	1-Pentanol	72799	725170.6
C7	2-Butanone, 3-hydroxy-	120784	297109.9
C8	Ethylbenzene	97	931.2
C9	Pyrazine, methyl-	401	4488.4
C10	2-Heptanone	493	20820.2
C11	Styrene	100456	178637.0
C12	1-Hexanol	34020	72964.4
C13	Cyclotetrasiloxane, octamethyl-	32890	78732.0
C14	Octanal	688070	784085.9
C15	1-Heptanol	58183	188106.3
C16	1 Octen 3 ol	58124	148939.5
C17	Pyrazine, trimethyl-	23952	74778.8
C18	Benzaldehyde	829241	1431876.4
C19	1-Hexanol, 2-ethyl-	9027	35017.8
C20	3,4-DihydrooxyphenylalanineI 4tms	236	1900.1
C21	2 Octenal	15576	48222.8
C22	Pyrazine, 2-ethyl-3,5-dimethyl-	1153	4705.3
C23	Nonanal	1248114	1543266.9
C24	1-Octanol	44252	119844.6
C25	Benzeneacetaldehyde	23258	57986.1
C26	Ethanol, 2-(hexyloxy)-	3618	15108.2
C27	Acetophenone	7312	23146.6
C28	Nonenal	25790	67558.0
C29	Benzene, 1,3-bis(1,1-dimethylethyl)-	115810	159161.0
C30	Pentane	369	4091.5
C31	Carbon disulfide	16707	83271.7
C32	1-Butanol	5353	46474.5
C33	1-Decanol	700	5176.9
C34	N Heptanal	347547	692014.9
C35	3-Furaldehyde	577	3005.5
C36	2-Heptenal	3283	12894.2
C37	2,3-Octanedione	30649	78244.3

Table 12 (con't). Overall means (n=186) and standard deviation values for volatile, aromatic chemicals identified by the GC/mass spectrometer.

Code:	Volatile, Aromatic Chemical	Mean	Standard deviation
C38	1-Octen-3-ol	37843	65101.9
C40	2-Doceden-1-al	1318	7980.6
C41	2(3H)-Furanone, dihydro-	10863	19517.0
C42	Bicyclo[3.2.0]heptan-2-one	312	2492.7
C43	(R)-(-)-14-Methylhexadec-8-Enal	113	1116.6
C44	Decanal	57395	93875.8
C45	Hexanoic acid	12468	37058.0
C46	3-(Hydroxyphenylmethyl)-2-methyl-3-buten-1-ol	422	2526.6
C47	Sulfur dioxide	13297	83829.0
C48	2-Butanone	17495	120516.3
C50	Benzene, 1,4-dimethyl-	125	1245.5
C51	Acetic acid	37832	68890.0
C52	Trisulfide, dimethyl	15756	84562.6
C54	2-Nonenal	14107	41704.4
C55	2-pentyl-4,5-dimethyloxazole	7681	25980.3
C57	Propanedioic acid, propyl-	251	2119.8
C58	Thiourea	4087	22965.1
C60	Benzene, ethyl-	1440	7197.5
C61	2-Propanone, 1-(acetyloxy)-	3210	16941.2
C62	Furan, 2-pentyl-	45629	102401.8
C63	4-Hydroxymandelic acid-tritms	753	5014.6
C64	2-Octenal	17652	41110.0
C65	Oxime-, methoxy-phenyl-	220	2257.9
C66	Ethanone, 1-phenyl-	14265	27848.2
C67	Decane	3333	14777.7
C69	Nonadecane	1447	6340.9
C70	Tetratetracontane	115	1138.4
C72	Dimethyl sulfide	2087	7222.6
C73	Pentanal	88324	271007.9
C74	Furfural	444	2540.0
C75	dl-Limonene	6426	44939.9
C77	Pyrazine, 3-ethyl-2,5-dimethyl-	7603	30800.1
C78	Dodecane	21827	82923.5
C79	Undecane, 2,6-dimethyl-	490	3547.5
C80	Tridec-12-en-2-one	101	971.4
C82	Heptanoic acid	2336	11354.8
C83	3-DODECEN-1-AL	9483	34310.5
C84	2-Methylene cyclopentanol	840	5774.2

Table 12 (con't). Overall means (n=186) and standard deviation values for volatile, aromatic chemicals identified by the GC/mass spectrometer.

Code:	Volatile, Aromatic Chemical	Mean	Standard deviation
C86	Dodecanal	28945	140142.8
C87	Dodecane, 2,6,10-trimethyl-	2943	36874.2
C90	Methane, thiobis-	10199	27710.5
C91	2,4,6-Triamino-5-pyrimidinyl hydrogen sulfate	2093	13851.2
C92	Pyrazine, 2,5-dimethyl-	38360	146154.0
C94	Pyrazine, 2,3-dimethyl-	3633	23077.7
C96	Propanal, 3-(methylthio)-	7774	18173.8
C97	Pyrazine, 2-ethyl-6-methyl-	2791	21399.4
C98	Trans-2-dodecenal	1239	7826.2
C99	2-Nonanone	4693	22618.4
C100	2-Acetylthiazole	2018	8013.7
C101	Phenyl acetaldehyde	5740	13343.6
C102	2-Decanone	3481	17330.5
C103	Ethanone, 1-(4,5-dihydro-2-thiazolyl)-	5939	19875.7
C105	2-Decenal	24551	81606.4
C106	Ethanone, 1-(1H-pyrrol-2-yl)-	2863	18069.1
C109	S-2-[4-Succinimidobutylamino]ethyl thiosulfuric acid	393	2931.7
C110	Heptane	5833	25186.1
C111	Benzene	174	1379.8
C112	2-Cyclohexen-1-ol	249	2087.3
C114	Heptanol	3419	14551.6
C116	Pentasiloxane, 1,1,3,3,5,5,7,7,9,9-decamethyl-	98	948.2
C117	Pentafluoropropionic acid, octyl ester	6196	43746.2
C118	Azocine, 1,2,3,4,7,8-hexahydro-	270	3168.1
C119	Methanethiol	3524	14589.7
C120	2-Aminoethyl hydrogen sulfate	553	4469.7
C121	1,3,5,7-Cyclooctatetraene	3444	27141.8
C122	2-Methyl-5-(4'-methylphenyl)sulfonyl-4-nitroimidazole	1055	13016.1
C123	Heptenal	1062	5513.9
C124	Sulfilimine, S,S-dimethyl-N-(4-nitrophenyl)-	364	3050.3
C128	2,3,5-Trimethyl pyrazine	2657	18259.0
C129	Butyrolactone	1538	5638.8
C131	Benzenepropanal, 4-(1,1-dimethylethyl)-	238	1890.1
C132	Tridecanal	822	7907.4
C133	Hentriacontane	2151	5668.7
C134	Tetradecanal	10723	49626.1
C135	Octacosane	226	1596.7
C138	n-Caproic acid vinyl ester	3222	31738.3

Table 12 (con't). Overall means (n=186) and standard deviation values for volatile, aromatic chemicals identified by the GC/mass spectrometer.

Code: Volatile, Aromatic Chemical	Mean	Standard deviation
C139 .Delta.-(2)-dodecanol	275	1932.0
C140 Aloxiprin	485	3934.4
C141 Benzene, propyl-	1202	5740.5
C144 Hexadecane	519	3331.7
C145 Hydroxylamine, O-decyl-	425	2402.6
C146 Cyclooctane	1973	19144.3
C147 3,3',5,5'-Tetramethoxy-2,2',4,4',6,6'-hexanitro-biphenyl	208	1472.5
C150 Undecanal	1848	15739.7
C151 Tetradecane	2951	23805.0
C152 Dodecane, 2-methyl-	2123	23558.7
C154 2-Furancarboxaldehyde	1542	7052.4
C155 3-(4-Tertiobutylphenyl)-propanal	184	1777.2
C158 Methyl 4-amino-3-(1',2',3',4'-tetrahydro-2',4'-dioxopyrimidin-1'-yl)thiop hen...	1099	4967.3
C159 Acetone	10504	62441.1
C160 S-2-[2-Succinimidoethylamino]ethyl thiosulfuric acid	234	1675.7
C161 2-Pentanone	2399	12702.1
C162 1,2-Cyclopentanediol, trans-	226	2060.6
C163 1-[2-(2-Methylbutyl)phenyl]ethanone	420	4084.8
C164 Butane, 2-methyl-	537	3992.6
C166 2-Propanone	48073	109477.9
C167 (N-(-2-Acetamido))-2-aminoethanesulfonic acid	474	4940.4
C170 Pyrazine, 2-ethyl-5-methyl-	3442	20318.9
C171 unidentified C2-benzene	436	3595.5
C172 2-Hexenal	13506	10777.2
C173 Acetaldehyde	15606	8619.7
C174 Heptanal	207423	541848.9
C175 1-Octen-3-one	664	4763.0
C176 Propanal, 2-methyl-	27674	18570.2
C177 Benzeneethanamine, N-[(4-hydroxy)hydrocinnamoyl]-	959	12267.2
C181 Cyclopentanol	1271	16070.8
C182 Benzene, (1-methylethyl)-	373	3390.9
C183 Cyclopropane, propyl-	1884	14526.5
C184 2-Undecanone	119	1141.4
C185 3-(3-Carboxy-4-hydroxyphenyl)-D-alanine	94	904.0
C186 Acetic acid, decyl ester	338	3122.4
C188 Nonahexacontanoic acid, methyl ester	98	942.4
C189 Butanoic acid	21114	145297.3

Table 12 (con't). Overall means (n=186) and standard deviation values for volatile, aromatic chemicals identified by the GC/mass spectrometer.

Code: Volatile, Aromatic Chemical	Mean	Standard deviation
C190 Ethyl 3-[(phenacetyl)amino]propane-1-(dithio)-oate	1164	8591.3
C192 1-Hexadecanol	439	3967.7
C194 1,3-Octadiene	1223	11868.3
C196 Cyclohexane, methyl-	1320	8141.3
C197 3,4-Dihydropyran	344	3290.9
C198 .Alpha.-Pinene, (-)-	1147	12272.7
C201 Cysteic acid	350	3389.4
C202 2-Acetyl-2-thiazoline	1419	6699.1
C203 Acetic acid ethenyl ester	8176	48359.3
C204 3-Penten-2-one, 4-methyl-	2995	15480.7
C205 Xylene	279	2689.0
C207 Cyclooctene	455	4394.6
C208 N,N'-Nonamethylenebis[-S-3-aminopropyl thiosulfuric acid]	617	4941.4
C210 1,3-Pentadiene	179	1772.6
C212 Nonacosane	340	1765.9
C214 D-Allose	304	2938.7
C215 Dimethyl trisulfide	1597	9587.7
C217 2,5-Octanedione	5755	35300.4
C218 2-Dodecenal	1382	12574.1
C219 Benzene, 1,4-bis(1,1-dimethylethyl)-	2544	16993.1
C220 1,1,1,3,3,5,5,7,7-Nonamethyltetrasiloxane	1483	14287.1
C222 Phenol, 4-methyl-	14106	170670.3
C223 Pentasiloxane, dodecamethyl-	1642	15108.7
C224 dimer of Coleon F	530	3662.7
C226 6-Methyl-5-hepten-2-one	117	1128.0
C227 2 Ethyl hexanol	1081	6233.8
C228 Eicosane, 10-methyl-	228	1809.5
C229 1-Dotriacontanol	107	1069.0
C232 2-Undecanone, 6,10-dimethyl-	116	1141.0
C233 (RS)-n-Hexadecyl trifluoromethyl carbinol	313	1749.1
C247 Propanoic acid	3894	52461.0
C250 Undecane	3053	32284.1
C251 Undecane, 5-methyl-	1241	12970.3
C256 Oxirane, phenyl-	485	3318.7
C258 Tetradecane, 2,6,10-trimethyl-	307	2657.7
C260 Hexatriacontane	256	2844.7
C261 14-.Beta.-H-pregna	246	2471.4

Table 12 (con't). Overall means (n=186) and standard deviation values for volatile, aromatic chemicals identified by the GC/mass spectrometer.

Code:	Volatile, Aromatic Chemical	Mean	Standard deviation
C267	Tridecane	9195	67953.4
C269	10-Methylnonadecane	1617	19223.5
C270	Eicosane	1452	13536.1
C276	Formic acid, hexyl ester	1115	11123.0
C277	2(5H)-Furanone, 3-methyl-	2238	28782.8
C285	2,5-Hexanedione	2038	23894.6
C286	trans-1,2-Di(1-methylethyl)cyclopropane	561	6471.3
C289	(Tetrahydroxycyclopentadienone)tricarbonyliron(0)	784	4383.9
C291	Pyrimidine, 4,6-dimethyl-	172	1659.0
C292	Octyl formate	1488	11751.0
C296	Cycloheptane	1577	11545.8
C299	6-Methoxy-2,2-dimethyl-3-chromene	381	2824.3
C302	4-t-Butyl-3-cyano-6-methyl-2(1H)-pyridinone	1154	12223.3
C303	Octane, 2-chloro-	20	1208.4
C306	Bicyclo[4.2.0]octa-1,3,5-triene	1095	11371.0
C308	Furan, 2,3-dihydro-4-methyl-	121	1182.3
C309	2(5H)-Furanone	562	5614.5
C310	Tridecanone-dimethylhydrazone	258	2779.6
C313	Hexane, 2,5-dimethyl-	2715	24102.4
C315	Octane	437	4247.1
C316	Toluene	605	5954.6
C324	1-Tridecanol	625	5745.5
C325	Octadecanal	1393	13042.6
C326	Pentadecane	893	9171.4
C332	Benzenemethanol	6766	65926.2
C333	Cyclohexanol	684	5397.9
C334	4-Octen-3-one	227	2557.8
C335	1-Hydroxyundecan-10-one	168	1337.3
C337	Trans-2-tridecenal	5397	37125.5
C338	unidentified C3-benzene	385	3075.6
C342	Pentatriacontane	203	2002.0
C344	1-Heptene	201	1975.4
C345	n-Heptane from 3-Heptene	2250	26549.8
C347	4-Pentenal	1428	14146.3
C348	Aloxiprin	936	6555.3
C350	1-Nonanol	302	2550.7
C352	Benzophenone	234	1859.9
C353	Pyrazine, 3,5-diethyl-2-methyl-	290	3253.8

Table 12 (con't). Overall means (n=186) and standard deviation values for volatile, aromatic chemicals identified by the GC/mass spectrometer.

Code: Volatile, Aromatic Chemical		Mean	Standard deviation
C358	Formic acid, heptyl ester	673	5584.0
C363	1-Tetradecanol	91	877.2
C364	2-Dodecanone	112	1092.6
C368	2-Pentanone, 4-hydroxy-4-methyl-	609	3813.4
C372	Docosane	210	2036.0
C373	Hexyl chloroformate	1531	10409.2
C374	Undecenal	1889	16583.1
C376	Hexadecanal	3173	31764.5
C382	1,1-Dodecanediol, diacetate	1217	9193.3
C389	Pyrazine, 2,5-dimethyl-3-(3-methylbutyl)-	278	2856.8
C390	Propane, 2-(ethenyloxy)-	1592	14279.5
C393	Nonane	149	1551.9
C399	Octenal	667	6425.4
C405	Benzene, methyl-	1156	1116.2
C407	2H-Azepin-2-one, hexahydro-1-methyl-	386	3711.5
C422	2,4-Decadienal, (E,E)-	384	4482.5
C423	2-Methyl-2-cyclopenten-1-ol	942	9411.9
C424	3-Octanone	411	5611.1
C434	Ethanimidic acid, ethyl ester	343	3317.1
C445	2-Octanone	261	2931.4
C456	Butanal	1912	23682.1
C498	Methoxyacetic acid, 2-tetradecyl ester	279	3186.4
C532	E-2-Decenal	665	7061.5

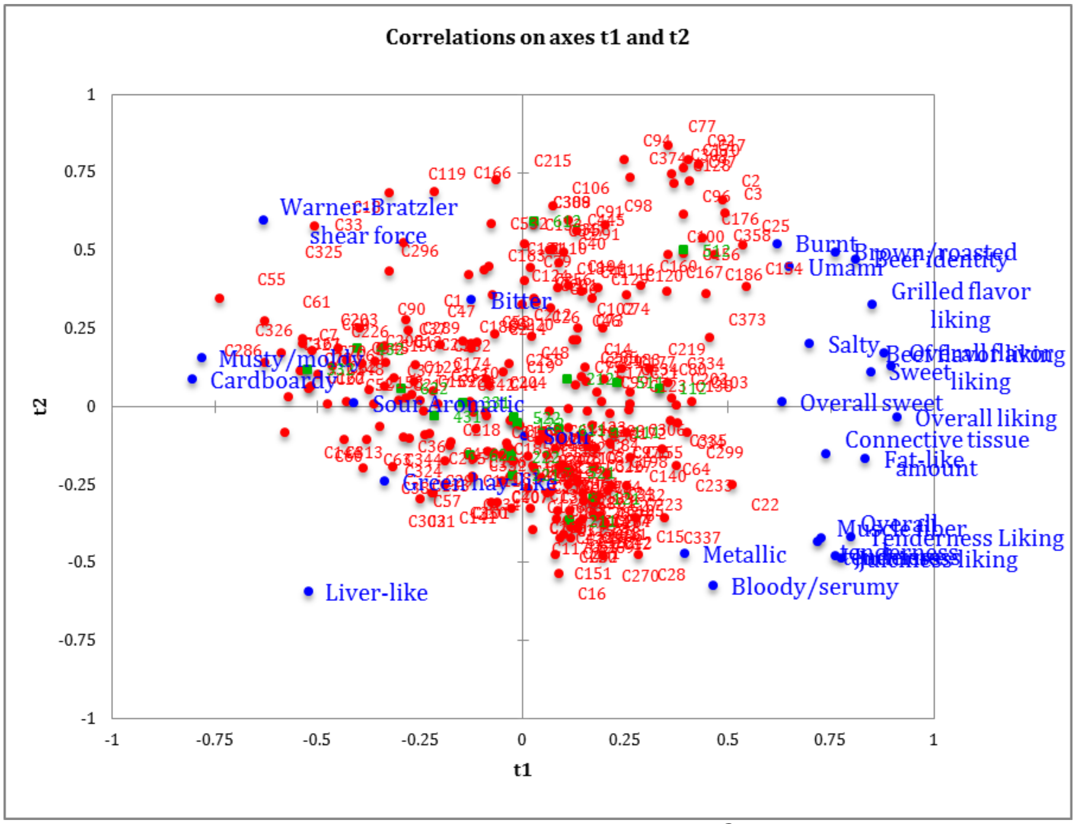

Figure 5. Partial least squares regression biplot (R^2=0.87) of trained descriptive flavor attributes from the Beef Lexicon (in blue), consumer sensory attributes (in black) , 160 volatile aromatic compounds (in red) and 20 treatments (in green) where 111 = tenderloin steaks grilled to 58°C; 112 = tenderloin steaks grilled to 80°C; 121 = tenderloin steaks George Foreman to 58°C; 122 = tenderloin steaks George Foreman to 80°C; 211 = high pH top loin steaks grilled to 58°C; 212 = high pH top loin steaks grilled to 80°C; 221 = high pH top loin steaks George Foreman to 58°C; 222 = high pH top loin steaks George Foreman to 80°C; 331 = Choice bottom round roasts cooked in a crockpot to 58°C; 332 = Choice bottom round roasts cooked in a crockpot to 80°C; 431 = Select bottom round roasts cooked in a crockpot to 58°C; 432 = Select bottom round roasts cooked in a crockpot to 80°C; 511 = Choice top loin steaks grilled to 58°C; 512 = Choice top loin steaks grilled to 80°C; 521 = Choice top loin steaks George Foreman to 58°C; 522 = Choice top loin steaks George Foreman to 80°C; and 611 = Select top sirloin steaks grilled to 58°C; 612 = Select top sirloin steaks grilled to 80°C; 621 = Select top sirloin steaks George Foreman to 58°C; 622 = Select top sirloin steaks George Foreman to 80°C.

Table 13. Stepwise linear regression for prediction of consumer overall like as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables[a]	Estimate[b] x 10^{-4}	Partial R^2	Equation R^2
	Intercept	5.45097		
1	C18 Benzaldehyde		0.07	0.07
2	C100 2-Acetylthiazole		0.06	0.12
3	C154 2-Furancarboxaldehyde		0.05	0.17
4	C325 Octadecanal		0.03	0.20
5	C25 Benzeneacetaldehyde		0.04	0.24
6	C177 Benzeneethanamine, N-[(4-hydroxy)hydrocinnamoyl]		0.02	0.26
7	C172 2-Hexenal		0.02	0.28
8	C276 Formic acid, hexyl ester		0.02	0.30
9	C61 2-Propanone, 1-(acetyloxy)		0.02	0.32
10	C352 Benzophenone		0.02	0.34
11	C332 Benzenemethanol		0.02	0.35
12	C58 Thiourea		0.01	0.36
13	C139 Delta.-(2)-dodecanol		0.01	0.38
14	C232 2-Undecanone, 6,10-dimethyl		0.01	0.39
15	C350 1-Nonanol		0.01	0.41
16	C122 2-Methyl-5-(4'-methylphenyl)sulfonyl-4-nitroimidazole		0.01	0.42
17	C324 1-Tridecanol		0.01	0.43
18	C91 2,4,6-Triamino-5-pyrimidinyl hydrogen sulfate		0.01	0.44
19	C261 14-.Beta.-H-pregna		0.01	0.45
20	C434 Ethanimidic acid, ethyl ester		0.01	0.47
21	C233 (RS)-n-Hexadecyl trifluoromethyl carbinol		0.01	0.48
22	C229 1-Dotriacontanol		0.01	0.49
23	C4 Hexanal		0.01	0.50
24	C19 1-Hexanol, 2-ethyl-		0.01	0.52
25	C117 Pentafluoropropionic acid, octyl ester		0.01	0.53
26	C27 Acetophenone		0.01	0.54
27	C134 Tetradecanal		0.02	0.56
28	C128 2,3,5-Trimethyl pyrazine		0.01	0.57
29	C40 2-Doceden-1-al		0.01	0.58
30	C373 Hexyl chloroformate		0.01	0.59
31	C364 2-Dodecanone		0.01	0.60
32	C256 Oxirane, phenyl-		0.01	0.61
33	C220 1,1,1,3,3,5,5,7,7-Nonamethyltetrasiloxane		0.01	0.62

Table 13 (con't). Stepwise linear regression for prediction of consumer overall like as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables[a]	Estimate[b] x 10^{-4}	Partial R^2	Equation R^2
34	C368 2-Pentanone, 4-hydroxy-4-methyl-		0.01	0.63
35	C133 Hentriacontane		0.01	0.64
36	C17 Pyrazine, trimethyl-		0.01	0.65
37	C363 1-Tetradecanol		0.01	0.65
38	C167 (N-(-2-Acetamido))-2-aminoethanesulfonic acid		0.01	0.66
39	C64 2-Octenal		0.01	0.67
40	C217 2,5-Octanedione		0.01	0.67
41	C159 Acetone		0.01	0.68
42	C145 Hydroxylamine, O-decyl-		0.01	0.69
43	C204 3-Penten-2-one, 4-methyl-		0.01	0.69
44	C69 Nonadecane		0.01	0.70
45	C291 Pyrimidine, 4,6-dimethyl-		0.01	0.71
46	C163 1-[2-(2-Methylbutyl)phenyl]ethanone		0.01	0.71
47	C302 4-t-Butyl-3-cyano-6-methyl-2(1H)-pyridinone		0.01	0.72
48	C160 S-2-[2-Succinimidoethylamino]ethyl thiosulfuric acid		0.01	0.72

[a]Estimates are the b-values for the final regression equation when the defined variable was included.

Table 14. Stepwise linear regression for prediction of beef flavor identity as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		5.42		
1	C2 Butanal, 3-methyl-	0.02	0.11	0.11
2	C22 Pyrazine, 2-ethyl-3,5-dimethyl-	0.42	0.06	0.16
3	C174 Heptanal	0.005	0.04	0.20
4	C434 Ethanimidic acid, ethyl ester	0.43	0.03	0.23
5	C25 Benzeneacetaldehyde	0.08	0.03	0.27
6	C48 2-Butanone	0.008	0.02	0.32
7	C144 Hexadecane	-0.39	0.02	0.36
8	C183 n-Caproic acid vinyl ester	0.09	0.02	0.38
9	C77 Pyrazine, 3-ethyl-2,5-dimethyl-	0.13	0.02	0.40
10	C94 Pyrazine, 2,3-dimethyl-	-0.11	0.02	0.42
11	C326 Pentadecane	-0.25	0.03	0.44
12	C177 Benzeneethanamine, N-[(4-hydroxy)hydrocinnamoyl]-	0.12	0.02	0.46
13	C258 Tetradecane, 2,6,10-trimethyl-	0.65	0.02	0.48
14	C147 3,3',5,5'-Tetramethoxy-2,2',4,4',6,6'-hexanitro-biphenyl	0.83	0.02	0.50
15	C456 Butanal	-0.24	0.01	0.51
16	C382 1,1-Dodecanediol, diacetate	-0.12	0.01	0.52
17	C41 2(3H)-Furanone, dihydro-	0.07	0.01	0.53
18	C117 Pentafluoropropionic acid, octyl ester	-0.03	0.01	0.55
19	C28 Nonenal	0.03	0.02	0.57
20	C12 1-Hexanol	-0.03	0.01	0.57
21	C299 1-Dotriacontanol	0.30	0.01	0.58
22	C226 6-Methyl-5-hepten-2-one	-0.70	0.01	0.59
23	C176 Propanal, 2-methyl-	-0.11	0.01	0.60
24	C1 2,3-Butanedione	0.005	0.01	0.61
25	C296 Cycloheptane	-0.17	0.01	0.62
26	C289 Tetrahydroxycyclopentadienone)tricarbonyliron(0)	-0.23	0.01	0.63
27	C79 Undecane, 2,6-dimethyl-	0.20	0.01	0.64
28	C139 Delta.-(2)-dodecanol	0.34	0.01	0.64
29	C363 1-Tetradecanol	1.05	0.01	0.65
30	C160 S-2-[2-Succinimidoethylamino]ethyl thiosulfuric acid	0.35	0.01	0.65
31	C26 Ethanol, 2-(hexyloxy)-	0.05	0.01	0.66
32	C75 dl-Limonene	-0.03	0.005	0.67

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 15. Stepwise linear regression for prediction of brown/roasted as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
Intercept		0.96		
1	C92 Pyrazine, 2,5-dimethyl-	-0.24	0.13	0.13
2	C434 Ethanimidic acid, ethyl ester	0.12	0.06	0.25
3	C22 Pyrazine, 2-ethyl-3,5-dimethyl-	-0.12	0.05	0.30
4	C80 Tridec-12-en-2-one	0.07	0.03	0.33
5	C18 Benzaldehyde	0.005	0.02	0.36
6	C498 Methoxyacetic acid, 2-tetradecyl ester	-1.5	0.02	0.38
7	C51 Acetic acid	-0.13	0.02	0.40
8	C160 S-2-[2-Succinimidoethylamino]ethyl thiosulfuric acid	0.19	0.02	0.41
9	C276 Formic acid, hexyl ester	-0.48	0.02	0.43
10	C456 Butanal	0.13	0.02	0.44
11	C25 Benzeneacetaldehyde	0.03	0.02	0.47
12	C16 1 Octen 3 ol	0.13	0.02	0.49
13	C57 Propanedioic acid, propyl-	0.54	0.02	0.51
14	C325 Octadecanal	-0.24	0.02	0.52
15	C335 1-Hydroxyundecan-10-one	-0.09	0.01	0.54
16	C342 Pentatriacontane	0.09	0.01	0.55
17	C9 Pyrazine, methyl-	-0.25	0.01	0.57
18	C177 Pentafluoropropionic acid, octyl ester	0.08	0.01	0.58
19	C176 Propanal, 2-methyl-	-0.02	0.01	0.59
20	C144 Hexadecane	-0.001	0.01	0.60
21	C188 Nonahexacontanoic acid, methyl ester	0.05	0.01	0.62
22	C48 2-Butanone	0.42	0.01	0.64
23	C11 Styrene	0.04	0.01	0.66
24	C145 Hydroxylamine, O-decyl-	0.44	0.01	0.67
25	C358 Formic acid, heptyl ester	-0.21	0.01	0.67
26	C30 Pentane	-0.39	0.01	0.68
27	C267 Tridecane	0.16	0.01	0.69
28	C32 1-Butanol	0.88	0.01	0.70
29	C183 Cyclopropane, propyl-	-0.93	0.01	0.71
30	C229 1-Dotriacontanol	1.79	0.01	0.71
31	C151 Tetradecane	0.08	0.01	0.72
32	C69 Nonadecane	0.23	0.01	0.73
33	C133 Hentriacontane	-0.005	0.01	0.73
34	C64 Pyrazine, 2,3-dimethyl-	0.61	0.01	0.74
35	C174 Heptanal	-0.15	0.01	0.75
36	C373 Hexyl chloroformate	1.23	0.01	0.75

Table 15 (con't). Stepwise linear regression for prediction of brown/roasted as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
37	C308 Furan, 2,3-dihydro-4-methyl-	-0.21	0.01	0.76
38	C40 2-Doceden-1-al	-0.83	0.01	0.76
39	C10 2-Heptanone	0.18	0.005	0.77
40	C33 1-Decanol	-0.003	0.005	0.77
41	C26 Ethanol, 2-(hexyloxy)-	0.04	0.004	0.78
42	C37 2,3-Octanedione	0.1	0.01	0.78
43	C83 3-DODECEN-1-AL	0.65	0.01	0.79
44	C135 Octacosane	-0.01	0.01	0.79
45	C163 1-[2-(2-Methylbutyl)phenyl]ethanone	-0.06	0.005	0.80
46	C291 Pyrimidine, 4,6-dimethyl-	-0.17	0.01	0.81
47	C182 Benzene, (1-methylethyl)-	0.2	0.005	0.81

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation..

Table 16. Stepwise linear regression for prediction of bloody/serumy as the dependent variable and aromatic volatile compounds as independent variables.

Variables[a]		Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
Intercept		1.60		
1	C55 2-pentyl-4,5-dimethyloxazole	-0.10	0.05	0.05
2	C69 Nonadecane	-0.29	0.04	0.09
3	C31 Carbon disulfide	0.04	0.05	0.14
4	C98 Trans-2-dodecenal	-0.23	0.03	0.16
5	C70 Tetratetracontane	-0.005	0.03	0.20
6	C344 1-Heptene	0.72	0.02	0.21
7	C203 Acetic acid ethenyl ester	-0.02	0.02	0.24
8	C19 1-Hexanol, 2-ethyl-	-0.04	0.02	0.25
9	C171 unidentified C2-benzene	-0.54	0.02	0.28
10	C306 Bicyclo[4.2.0]octa-1,3,5-triene	0.26	0.01	0.30
11	C190 Ethyl 3-[(phenacetyl)amino]propane-1-(dithio)-oate	0.14	0.01	0.35
12	C17 Pyrazine, trimethyl-	0.03	0.01	0.36
13	C18 Benzaldehyde	-0.001	0.01	0.38
14	C207 Cyclooctene	0.37	0.01	0.39
15	C15 1-Heptanol	0.005	0.01	0.40
16	C214 D-Allose	-0.40	0.01	0.41
17	C114 Heptanol	0.12	0.01	0.42
18	C45 Hexanoic acid	0.03	0.01	0.43
19	C232 2-Undecanone, 6,10-dimethyl-	-0.79	0.01	0.44
20	C164 Butane, 2-methyl-	0.48	0.01	0.44
21	C368 2-Pentanone, 4-hydroxy-4-methyl-	-0.32	0.01	0.45
22	C140 Aloxiprin	0.27	0.01	0.46
23	C338 unidentified C3-benzene	-0.29	0.01	0.47
24	C215 Dimethyl trisulfide	-0.18	0.01	0.47
25	C120 2-Aminoethyl hydrogen sulfate	0.34	0.01	0.48
26	C110 Heptane	-0.10	0.01	0.49
27	C83 3-DODECEN-1-AL	0.04	0.01	0.49
28	C217 2,5-Octanedione	0.04	0.01	0.49
29	C73 Pentanal	-0.006	0.01	0.50
30	C111 Benzene	0.86	0.01	0.51

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 17. Stepwise linear regression for prediction of descriptive sensory fat-like flavor as the dependent variable and aromatic volatile compounds as independent variables.

Variables[a]		Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
Intercept		1.04		
1	C18 Benzaldehyde	-0.007	0.05	0.05
2	C25 Benzeneacetaldehyde	-0.003	0.04	0.12
3	C350 1-Nonanol	0.5	0.03	0.15
4	C144 Hexadecane	0.02	0.03	0.18
5	C226 6-Methyl-5-hepten-2-one	-0.0007	0.02	0.20
6	C128 2,3,5-Trimethyl pyrazine	0.04	0.02	0.23
7	C434 Ethanimidic acid, ethyl ester	0.09	0.02	0.25
8	C258 Tetradecane, 2,6,10-trimethyl-	0.07	0.03	0.30
9	C41 2(3H)-Furanone, dihydro-	-0.04	0.01	0.33
10	C97 Pyrazine, 2-ethyl-6-methyl-	-0.02	0.02	0.35
11	C325 Octadecanal	-0.19	0.013	0.36
12	C11 Styrene	0.003	0.01	0.37
13	C1 2,3-Butanedione	0.05	0.01	0.40
14	C291 Pyrimidine, 4,6-dimethyl-	0.05	0.01	0.40
15	C163 1-[2-(2-Methylbutyl)phenyl]ethanone	0.12	0.02	0.42
16	C44 Decanal	-0.22	0.01	0.43
17	C139 Delta.-(2)-dodecanol	0.03	0.01	0.44
18	C6 1-Pentanol	-0.04	0.01	0.50
19	C77 Pyrazine, 3-ethyl-2,5-dimethyl-	-0.27	0.01	0.47
20	C26 Ethanol, 2-(hexyloxy)-	0.007	0.01	0.48
21	C188 Nonahexacontanoic acid, methyl ester	-0.1	0.01	0.50
22	C335 1-Hydroxyundecan-10-one	0.07	0.01	0.51
23	C313 Hexane, 2,5-dimethyl-	0.07	0.01	0.52
24	C299 6-Methoxy-2,2-dimethyl-3-chromene	0.1	0.01	0.53
25	C150 Undecanal	0.29	0.01	0.54
26	C315 Octane	-0.24	0.01	0.55
27	C276 Formic acid, hexyl ester	0.19	0.01	0.56
28	C64 2-Octenal	0.11	0.01	0.57
29	C9 Pyrazine, methyl-	-0.20	0.01	0.60
30	C172 2-Hexenal	0.15	0.02	0.60
31	C176 Propanal, 2-methyl-	-0.17	0.01	0.61
32	C66 Ethanone, 1-phenyl-	0.12	0.001	0.62
33	C373 Hexyl chloroformate	-0.05	0.01	0.63
34	C260 Hexatriacontane	1.36	0.01	0.64
35	C84 2-Methylene cyclopentanol	0.32	0.01	0.64

Table 17 (con't). Stepwise linear regression for prediction of descriptive sensory fat-like flavor as the dependent variable and aromatic volatile compounds as independent variables.

Variables[a]		Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
36	C352 Benzophenone	-0.57	0.01	0.65
37	C69 Nonadecane	0.31	0.01	0.66
38	C86 Dodecanal	-0.42	0.01	0.66
39	C46 3-(Hydroxyphenylmethyl)-2-methyl-3-buten-1-ol	0.06	0.01	0.67
40	C133 Hentriacontane	0.9	0.01	0.68
41	C368 2-Pentanone, 4-hydroxy-4-methyl-	0.28	0.01	0.69
42	C132 Tridecanal	-0.04	0.01	0.69
43	C67 Decane	0.18	0.01	0.70
44	C83 3-DODECEN-1-AL	-0.14	0.001	0.71
45	C376 Hexadecanal	0.6	0.01	0.72
46	C164 Butane, 2-methyl-	0.34	0.01	0.73
47	C372 Docosane	0.33	0.01	0.74
48	C48 2-Butanone	-0.29	0.005	0.74
49	C145 Hydroxylamine, O-decyl-	0.36	0.01	0.75
50	C45 Hexanoic acid	0.05	0.005	0.75
51	C197 3,4-Dihydropyran	-0.05	0.01	0.76
52	C175 1-Octen-3-one	-0.06	0.005	0.76
53	C399 Octenal	0.3	0.005	0.77

[a]estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

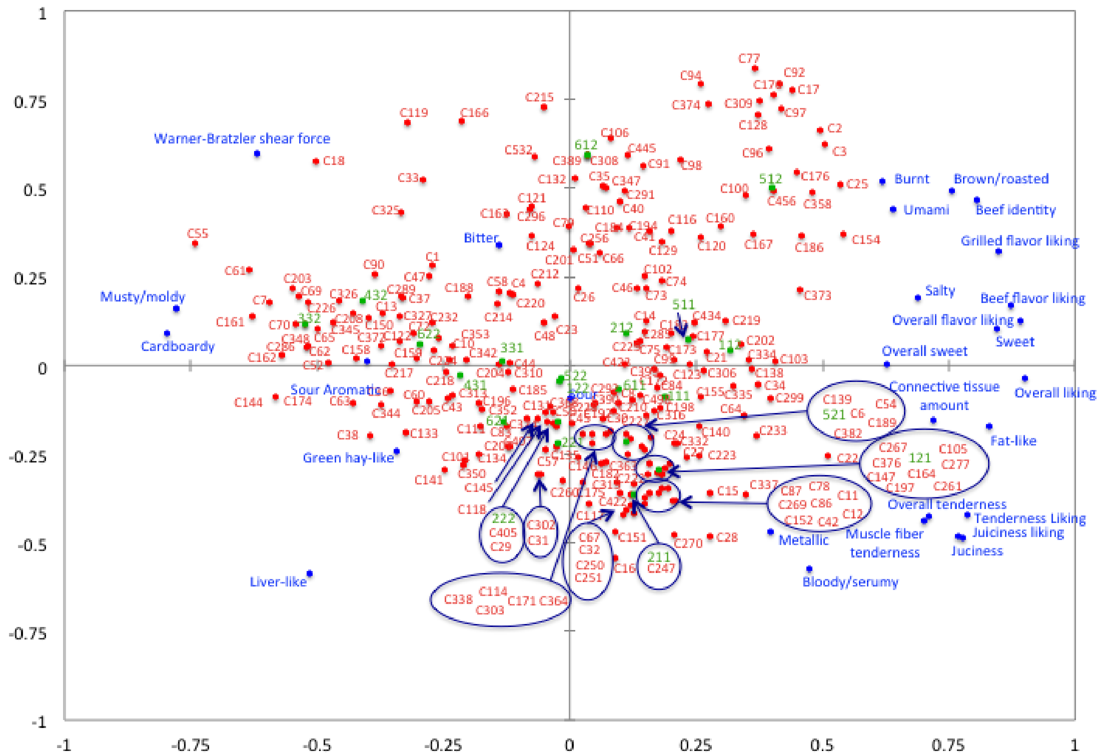

Figure 6. Partial least squares regression biplot (R^2=0.87) of trained descriptive flavor attributes from the Beef Lexicon and consumer sensory attributes (in blue), 234 volatile aromatic compounds (in red) and 20 treatments (in green) where 111 = tenderloin steaks grilled to 137°F; 112 = tenderloin steaks grilled to 176°F; 121 = tenderloin steaks George Foreman to 137°F; 122 = tenderloin steaks George Foreman to 176°F; 211 = high pH top loin steaks grilled to 137°F; 212 = high pH top loin steaks grilled to 176°F; 221 = high pH top loin steaks George Foreman to 137°F; 222 = high pH top loin steaks George Foreman to 176°F; 331 = Choice bottom round roasts cooked in a crockpot to 137°F; 332 = Choice bottom round roasts cooked in a crockpot to 176°F; 431 = Select bottom round roasts cooked in a crockpot to 137°F; 432 = Select bottom round roasts cooked in a crockpot to 176°F; 511 = Choice top loin steaks grilled to 137°F; 512 = Choice top loin steaks grilled to 176°F; 521 = Choice top loin steaks George Foreman to 137°F; 522 = Choice top loin steaks George Foreman to 176°F; and 611 = Select top sirloin steaks grilled to 137°F; 612 = Select top sirloin steaks grilled to 176°F; 621 = Select top sirloin steaks George Foreman to 137°F; 622 = Select top sirloin steaks George Foreman to 176°F.

Table 18. Stepwise linear regression for prediction of descriptive sensory metallic flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Variables[a]		Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
Intercept		1.79		
1	C55 2-pentyl-4,5-dimethyloxazole	-0.05	0.06	0.06
2	C220 1,1,1,3,3,5,5,7,7-Nonamethyltetrasiloxane	-0.07	0.04	0.10
3	C98 Trans-2-dodecenal	-0.14	0.03	0.13
4	C15 1-Heptanol	0.02	0.03	0.16
5	C45 Hexanoic acid	0.01	0.03	0.19
6	C201 Cysteic acid	-0.16	0.02	0.21
7	C69 Nonadecane	-0.09	0.02	0.24
8	C118 Azocine, 1,2,3,4,7,8-hexahydro-	-0.32	0.02	0.26
9	C114 Heptanol	0.06	0.02	0.27
10	C145 Hydroxylamine, O-decyl-	-0.31	0.01	0.29
11	C223 Pentasiloxane, dodecamethyl-	0.03	0.01	0.30
12	C58 Thiourea	-0.03	0.01	0.33
13	C232 2-Undecanone, 6,10-dimethyl-	-0.68	0.01	0.34
14	C164 Butane, 2-methyl-	0.08	0.01	0.35
15	C291 Pyrimidine, 4,6-dimethyl-	-0.42	0.01	0.36
16	C163 1-[2-(2-Methylbutyl)phenyl]ethanone	0.17	0.02	0.37
17	C159 Acetone	-0.01	0.01	0.39
18	C373 Hexyl chloroformate	0.05	0.01	0.40
19	C233 (RS)-n-Hexadecyl trifluoromethyl carbinol	0.26	0.01	0.41
20	C144 Hexadecane	0.22	0.01	0.42
21	C229 1-Dotriacontanol	-0.84	0.01	0.43
22	C41 2(3H)-Furanone, dihydro-	0.03	0.01	0.44
23	C40 2-Doceden-1-al	-0.10	0.01	0.45
24	C37 2,3-Octanedione	-0.02	0.01	0.45
25	C28 Nonenal	0.02	0.01	0.47
26	C105 2-Decenal	-0.03	0.01	0.49
27	C6 1-Pentanol	-0.003	0.01	0.50
28	C167 (N-(-2-Acetamido))-2-aminoethanesulfonic acid	-0.10	0.01	0.51
29	C96 Propanal, 3-(methylthio)-	0.03	0.01	0.52
30	C532 E-2-Decenal	0.14	0.01	0.53
31	C344 1-Heptene	0.62	0.01	0.54
32	C73 Pentanal	-0.003	0.01	0.55
33	C74 Furfural	0.36	0.01	0.56

Table 18 (con't). Stepwise linear regression for prediction of descriptive sensory metallic flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

	Variables[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
34	C22 Pyrazine, 2-ethyl-3,5-dimethyl-	-0.19	0.01	0.57
35	C399 Octenal	0.08	0.01	0.58
36	C79 Undecane, 2,6-dimethyl-	-0.19	0.01	0.58
37	C296 Cycloheptane	0.06	0.01	0.60
38	C212 Nonacosane	-0.20	0.01	0.61
39	C364 2-Dodecanone	0.49	0.01	0.61

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 19. Stepwise linear regression for prediction of descriptive sensory liver flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Variables[a]		Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
Intercept		0.4		
1	C376 Hexadecanal	0.14	0.05	0.05
2	C22 Pyrazine, 2-ethyl-3,5-dimethyl-	-0.22	0.05	0.01
3	C277 2(5H)-Furanone, 3-methyl-	-0.11	0.05	0.14
4	C98 Trans-2-dodecenal	-0.06	0.03	0.18
5	C123 Heptenal	-0.07	0.03	0.20
6	C164 Butane, 2-methyl-	0.10	0.02	0.23
8	C54 2-Nonenal	-0.02	0.02	0.27
9	C92 Pyrazine, 2,5-dimethyl-	-0.004	0.02	0.29
12	C291 Pyrimidine, 4,6-dimethyl-	0.62	0.02	0.32
13	C389 Pyrazine, 2,5-dimethyl-3-(3-methylbutyl)-	-0.32	0.03	0.34
15	C155 3-(4-Tertiobutylphenyl)-propanal	-0.21	0.01	0.37
16	C140 Aloxiprin	-0.12	0.01	0.39
17	C160 S-2-[2-Succinimidoethylamino]ethyl thiosulfuric acid	-0.21	0.01	0.40
18	C260 Hexatriacontane	0.61	0.01	0.41
19	C87 Dodecane, 2,6,10-trimethyl-	-0.17	0.01	0.43
20	C250 Undecane	0.15	0.01	0.44
21	C64 2-Octenal	-0.02	0.01	0.45
22	C382 1,1-Dodecanediol, diacetate	0.05	0.01	0.47
23	C103 Ethanone, 1-(4,5-dihydro-2-thiazolyl)-	-0.02	0.01	0.48
24	C86 Dodecanal	0.003	0.01	0.49
26	C302 4-t-Butyl-3-cyano-6-methyl-2(1H)-pyridinone	0.03	0.01	0.51
27	C166 2-Propanone	0.007	0.01	0.52
28	C18 Benzaldehyde	-0.0005	0.01	0.53
29	C184 2-Undecanone	-0.46	0.01	0.54
30	C185 3-(3-Carboxy-4-hydroxyphenyl)-D-alanine	0.42	0.01	0.54
31	C315 Octane	0.08	0.01	0.55
32	C226 6-Methyl-5-hepten-2-one	-0.31	0.01	0.56
33	C276 Formic acid, hexyl ester	-0.03	0.01	0.57
34	C173 Acetaldehyde	-0.04	0.01	0.57
35	C29 Benzene, 1,3-bis(1,1-dimethylethyl)-	0.004	0.01	0.60
38	C350 1-Nonanol	0.20	0.01	0.58
40	C218 2-Dodecenal	0.03	0.01	0.58
41	C333 Cyclohexanol	0.08	0.01	0.59

Table 19 (con't). Stepwise linear regression for prediction of descriptive sensory liver flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Variables[a]			Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
42	C158	Methyl 4-amino-3-(1',2',3',4'-tetrahydro-2',4'-dioxopyrimidin-1'-yl)thiop hen...	0.06	0.01	0.60
43	C132	Tridecanal	0.04	0.01	0.61

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 20. Stepwise linear regression for prediction of descriptive sensory umami flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Variables[a]		Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
Intercept				
1	C309 2(5H)-Furanone	0.11	0.05	0.05
2	C363 1-Tetradecanol	1.35	0.03	0.08
3	C198 Alpha.-Pinene, (-)-	0.09	0.03	0.11
4	C25 Benzeneacetaldehyde	0.04	0.03	0.14
5	C83 3-DODECEN-1-AL	-0.03	0.05	0.23
6	C220 1,1,1,3,3,5,5,7,7-Nonamethyltetrasiloxane	0.08	0.03	0.26
7	C57 Propanedioic acid, propyl	-0.46	0.03	0.29
8	C28 Nonenal	0.02	0.03	0.32
9	C313 Hexane, 2,5-dimethyl-	-0.02	0.03	0.34
10	C326 Pentadecane	-0.25	0.02	0.39
11	C276 Formic acid, hexyl ester	0.04	0.02	0.41
12	C434 Ethanimidic acid, ethyl ester	0.28	0.02	0.45
13	C158 Methyl 4-amino-3-(1',2',3',4'-tetrahydro-2',4'-dioxopyrimidin-1'-yl)thiop hen...	0.08	0.02	0.47
14	C204 3-Penten-2-one, 4-methyl-	-0.04	0.01	0.49
15	C80 Tridec-12-en-2-one	0.9	0.02	0.51
16	C390 Propane, 2-(ethenyloxy)-	-0.04	0.01	0.54
17	C164 Butane, 2-methyl-	-0.14	0.01	0.55
18	C69 Nonadecane	-0.1	0.01	0.56
19	C214 D-Allose	0.21	0.01	0.57
20	C96 Propanal, 3-(methylthio)-	0.04	0.01	0.58
21	C150 Undecanal	0.1	0.01	0.59
22	C14 Octanal	-0.002	0.01	0.6
23	C260 Hexatriacontane	0.45	0.01	0.6
24	C159 Acetone	0.009	0.01	0.61
25	C27 Acetophenone	-0.02	0.01	0.62
26	C42 Bicyclo[3.2.0]heptan-2-one	-0.25	0.01	0.64
27	C41 2(3H)-Furanone, dihydro-	0.05	0.01	0.64
28	C7 2-Butanone, 3-hydroxy-	-0.002	0.01	0.66
29	C51 Acetic acid	-0.009	0.01	0.67
30	C4 Hexanal	0.0004	0.01	0.68
31	C3 Butanal, 2-methyl-	-0.006	0.01	0.69
32	C233 (RS)-n-Hexadecyl trifluoromethyl carbinol	-0.2	0.01	0.71

Table 20 (con't). Stepwise linear regression for prediction of descriptive sensory umami flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Variables[a]		Estimate[a] x 10^{-4}	Partial R^2	Equation R^2
33	C208 N,N'-Nonamethylenebis[-S-3-aminopropylthiosulfuric acid]	-0.12	0.01	0.71
34	C161 2-Pentanone	0.02	0.007	0.72
35	C114 Heptanol	-0.02	0.01	0.73
36	C61 2-Propanone, 1-(acetyloxy)-	-0.06	0.01	0.73
37	C124 Sulfilimine, S,S-dimethyl-N-(4-nitrophenyl)-	-0.12	0.01	0.74
38	C160 S-2-[2-Succinimidoethylamino]ethyl thiosulfuric acid	-0.2	0.01	0.74
39	C185 3-(3-Carboxy-4-hydroxyphenyl)-D-alanine	-0.31	0.005	0.75
40	C16 1 Octen 3 ol	-0.008	0.004	0.75
41	C64 2-Octenal	0.02	0.01	0.76
42	C201 Cysteic acid	-0.15	0.01	0.77
43	C338 unidentified C3-benzene	-0.18	0.01	0.78
44	C128 2,3,5-Trimethyl pyrazine	0.02	0.005	0.78
45	C73 Pentanal	-0.002	0.005	0.78
46	C250 Undecane	-0.03	0.005	0.79
47	C256 Oxirane, phenyl-	0.18	0.01	0.79
48	C335 1-Hydroxyundecan-10-one	0.32	0.01	0.8
49	C217 2,5-Octanedione	0.02	0.01	0.8
50	C352 Benzophenone	-0.13	0.004	0.81
51	C172 2-Hexenal	-0.06	0.003	0.81
52	C48 2-Butanone	0.003	0.01	0.81
53	C167 (N-(-2-Acetamido))-2-aminoethanesulfonic acid	0.06	0.004	0.81
54	C66 Ethanone, 1-phenyl-	0.02	0.003	0.82
55	C106 Ethanone, 1-(1H-pyrrol-2-yl)-	-0.02	0.004	0.82
56	C84 2-Methylene cyclopentanol	-0.05	0.005	0.82

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

APPENDIX B

DEMOGRAPHICS AND BALLOT

Demographic questions included on the consumer ballot.

DEMOGRAPHICS

Respondent Number _______

Please circle each appropriate response.

1. Please indicate your gender.
   Male / Female
2. Which of the following best describes your age?
   20 years or younger / 21 - 25 years / 26 - 35 years / 36 - 45 years / 46 - 55 years / 56 - 65 years / 66 years and older
3. Which of the following best describes your household income?
   Below $25,000 / $25,001 - $49,999 / $50,000 - $74,999 / $75,000 - $99,999 / $100,000 or more
4. How many people live in your household including yourself?
   1 2 3 4 5 6 or more
5. Please indicate your employment level.
   Not employed / Part-time / Full-time
6. Please circle any of the following proteins that you eat either at home or at a restaurant (away from home).

At Home	**Away from Home/Restaurant**
Chicken	Chicken
Beef	Beef
Pork	Pork
Fish	Fish
Lamb	Lamb
Eggs	Eggs
Soy Based Products	Soy Based Products

7. How many times a week total do you consume the following protein sources?

Beef	0	1-2	3-4	5-6	7 or more
Pork	0	1-2	3-4	5-6	7 or more
Lamb	0	1-2	3-4	5-6	7 or more
Chicken	0	1-2	3-4	5-6	7 or more
Fish	0	1-2	3-4	5-6	7 or more
Soy Based Products	0	1-2	3-4	5-6	7 or more

8. What cooking method do you prefer to use when cooking a beef steak? Circle any that apply.
   Pan-frying or using a skillet on the stove / Stir Fry
   Grilling Outside / Oven Broiling
   Oven Baking / Microwave
   Electric Appliance (George Foreman Grill or other electric grill)
9. What degree of doneness to you prefer your steak to be cooked to?
   Rare / Medium Rare / Medium / Medium Well / Well / Very Well
10. When purchasing beef, what do you typically tend to buy at the retail store?
    Grass Fed / Dry Aged / Organic / Traditional beef at the retail store
11. What flavor or types of cuisines do you like, please circle all that apply?
    American / Barbeque / Mexican/Spanish / Indian / French
    Chinese / Greek / Japanese / Thai / Italian / Lebanese

Consumer ballot.

Order 1

Respondent Number _____ Group Time_____

Sample Number________ Date___________

Please take a bite of cracker followed by a sip of water prior to evaluating the product. Place a mark in the box that represents your answer for each of the following questions.

1. How much do you like or dislike this steak OVERALL?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | Neither Like or Dislike | Like Extremely

2. How much do you like or dislike of the OVERALL FLAVOR of this steak?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | Neither Like or Dislike | Like Extremely

3. How much do you like or dislike of the BEEFY FLAVOR of this steak?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | Neither Like or Dislike | Like Extremely

4. How much do you like or dislike of the GRILLED FLAVOR of this steak?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | Neither Like or Dislike | Like Extremely

5. How much do you like or dislike of the JUICINESS of this steak?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | Neither Like or Dislike | Like Extremely

6. How much do you like or dislike of the TENDERNESS of this steak?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | Neither Like or Dislike | Like Extremely

7. Please write any words that describe the POSITIVE or GOOD FLAVORS in this beef steak.

____

8. Please write any words that describe the NEGATIVE or BAD FLAVORS in this beef steak.